pF-Water Relation and Pore Size Distribution in Delhi Soil and Jumna Sand

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The porosity of soils has been a subject of extensive study by numerous workers. Porosity is related to the amounts of water held by a soil at zero and higher tensions and also the permeability of soil, for water. Leamer and Lutz (1940) have studied the pore size distribution in different soils and soil separates in relation to permeability. Baver (1938) has studied the pF-water curves of a large number of soils and has arrived at important conclusions relating permeability and the characteristics of pF-water curves.

A study of the pF-water relation and pore size distribution in Delhi soil and Jumna sand has been made and the relation between these properties and permeability has also been studied in this paper.

MATERIAL AND METHODS

Soil : The Gangetic alluvial soil of Delhi which was used in an earlier investigation (Rao *et al.* 1952, 1953 *a,b*) was employed in the present work. A sample of the sand from an extensive deposit of sand on the banks of Jumna river near Delhi (India) was collected.

Tensiometer technique : The tensiometer technique, described by Richards (1949) in his review article on the methods of measuring soil moisture tension, was employed. The experimental arrangement of the tensiometer is shown in Fig. 1. A porous porcelain cylinder fitted with the tensiometer tube was supported on an iron rod (one inch long) rivetted to the perforated bottom of a metallic can. With the iron rod support, the tensiometer could be placed in a stable position. Otherwise, if merely clamped the porcelain cylinder would be subjected to strain during drying of the soil. As a result of this, the rubber cork joint would yield and abrupt changes in tensiometer readings were often noticed.

A modification was effected in the apparatus by introducing a ground glass joint between the porous porcelain cylinder and the tensiometer tube. The object of this joint was to facilitate compaction of the loose soil while having the porcelain cylinder supported over the iron rod inside the soil. After the compaction was over, the tensiometer tube was attached and the tensiometer was brought into action by filling it with water. Without this joint the insertion of the tensiometer into the compacted soil would disturb the state of compaction. Before the porcelain cylinder was introduced into the soil, the air inside the pores was replaced by water. The tube filled with water was next inserted into the soil. The soil was compacted by dropping the can ten times over a height of one inch. The tensiometer tube was attached. The soil was next saturated with water by passing water through the soil from above for about 20 hours in order to remove the entrapped air from soil by solvent action. Permeability measurements (Rao *et al.* 1953*a*) have shown that the removal of entrapped air from soil is normally complete by about 24 hours.

The zero reading of the tensiometer was taken by adjusting the water table to the centre of the porcelain cylinder. After taking the zero reading, the water table was

removed and the drainable water was allowed to drain off through the perforated bottom. Two days after the removal of the water table, the first tension reading was taken and at the same time a sample of the soil was removed for determining water content. The soil water was determined by the method of oven drying. For nearly 6 hours before taking the tension reading and removal of the soil sample, the can was covered to check evaporation in order to avoid non-uniformity in water distribution in the entire soil bulk. The soil was next kept open for a day to facilitate the removal of water by evaporation and again covered for about 6 hours for the attainment of equilibrium before the next reading was taken. The measurements were continued in this way. Each experiment lasted over 3 to 4 weeks. Collection of air bubbles was noticeable only after a tension of 30-40 cm. of mercury was reached. Nearly 15 to 20 points were obtained in each experiment and only some of them are shown in the graph. Duplicate experiments were carried out in a few cases to ensure reproducibility of the results. According to Richards (1949), if the diameter of the mercury reservoir bulb is more than 10 times the diameter of the mercury column in the tensiometer, the fluctuation in the level of mercury in the reservoir is negligible. In the tensiometer used in this work, the diameter of the mercury reservoir bulb was 40 times the diameter of the capillary.

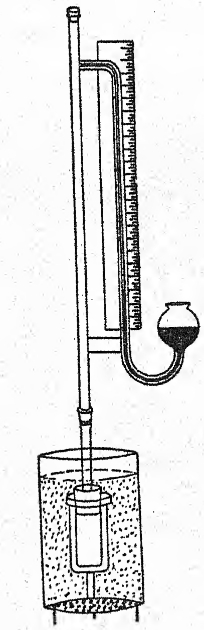


Fig. 1—Tensiometer

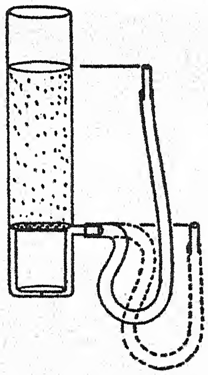
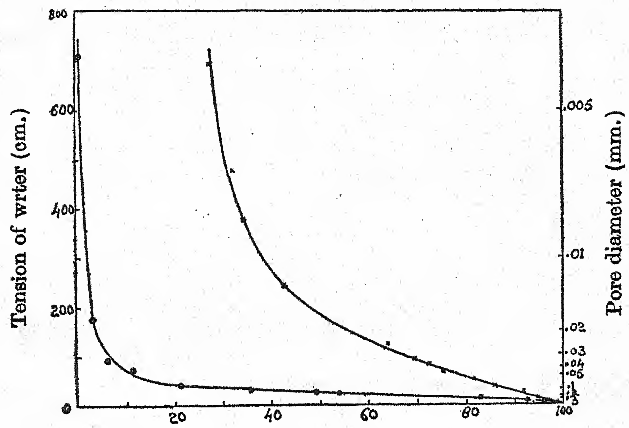


Fig. 2—Apparatus for measuring soil water at zero tension

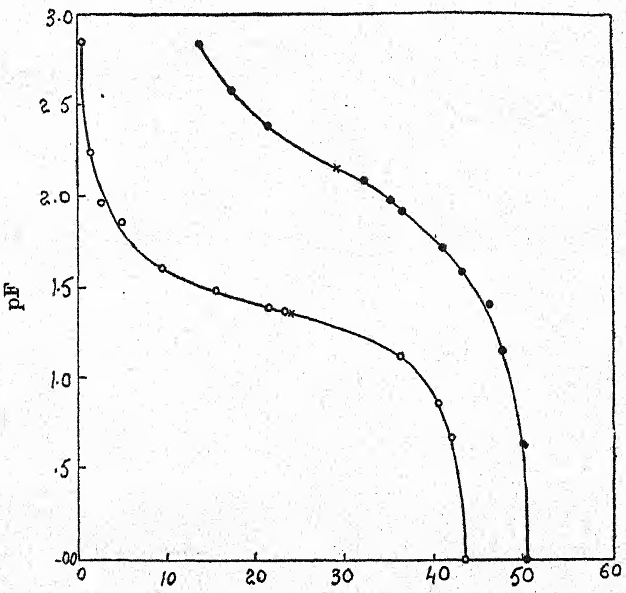
Determination of soil water at zero tension : For determining the soil water at zero tension, the method of oven drying a sample of the soil taken from the surface while keeping the water level at the surface of the soil was consistently giving higher and unsteady values. Therefore an alternative procedure was adopted. It consisted in employing a glass cylinder with a side tube at the bottom (Fig. 2). A column (same as the soil column in the tensiometer experiment) of known weight of soil was taken over the perforated metallic disc covered with a filter paper. The soil was compacted. Water was allowed to pass through the soil column for about 20 hours in the same way as in the tensiometer

experiment. The water table was kept at the surface of the soil by adjusting the side tube and the apparatus weighed. The weight of glass cylinder with water level at the porous disc was also determined. The weights of the cylinder with and without soil column being known, the percentage of water in soil at zero tension was calculated. The accuracy of this measurement was ±0.5%. From these experiments, the tension-water and pF-water relations were obtained for Delhi soil and Jumna sand and have been shown in Fig. 5 and 3.



Percentage water of saturation value at zero tension

FIG. 3—Water-tension relation in Delhi soil (×) and Jumna sand (o)



Weight of water per 100 c.c. of soil (●) and sand (O)

FIG. 5—pF-water relation in Delhi soil (●) and Jumna sand (O)

Inflexion point : The inflexion point in the pF-water curve is the point at which the rate of change is zero. This was determined by adopting the numerical method. In cases, in which the inflexion was an interval instead of a point, the centre of the interval was taken as the inflexion point.

Permeability coefficient : For determining the permeability coefficients of soil and sand, the permeability technique described in a previous paper (Rao *et al.* 1953*a*) was adopted.

Apparent density : In order to obtain the weight of water per 100 cc of soil or sand from the percentage on weight basis, it is necessary to know the apparent densities. The apparent densities of soil and sand were determined as follows.

A glass tube with flat edges and of known height and diameter was selected. One end was covered with a cellophane membrane. The tube was filled with soil or sand which was taken in excess over the height of the tube by fixing a paper cylinder temporarily to the top of the glass tube. After compacting the soil by dropping the tube ten times over a height of one inch in the same way as in permeability measurements, the paper cylinder was removed, excess of the soil was cut off by a razor blade and the weight determined. Knowing the weight of the tube and its volume, apparent density was calculated. The apparent densities of Delhi soil and Jumna sand are shown in table 1.

TABLE 1

	Weight of water per 100 cc. at zero tension	Weight of water per 100 cc. at inflexion point	pF of inflexion point	Weight of water per 100 cc. withdrawn from zero tension to inflexion point	Porosity factor	Premeability coeff. for water in cm. per hour	Apparent density
Delhi soil	50.44	29.5	2.15	20.94	9.74	5.6	1.258
Jumna sand	43.72	24.0	1.36	19.72	14.50	143.0	1.486

From the tensiometer studies with soil and sand, the tension-water and pF-water curves were drawn (Fig. 5 and 3). In drawing the tension-water curves, the percentage fraction of the amount of water held at zero tension by the soil or sand is plotted against tension in cm. of water. The pore diameters corresponding to the different tension values have been calculated (Leamer and Lutz, 1940) from the capillary rise formula, $h=\frac{2s}{rpg}$ which becomes, $d=\frac{3}{h}$ where 'd' is the diameter of the pore in mm. and 'h' the tension in cm. of water and these values of pore diameters have also been indicated in the graph of tension-water relation. In the graph of pF-water relation, the weight of water contained in 100 cc. of soil or sand is plotted against pF.

DISCUSSION

Tension-water relation: The tension-water relations in Delhi soil and Jumna sand have been indicated in Fig. 3. There is a distinct difference between the two curves. The pore volumes in the soil and sand are denoted by the amounts of water held by 100 cc. of each of these at zero tension and these are 50.44 gm. and 43.72 gm. respectively. Of these pore volumes only 6.5% remain filled in sand at 100 cm. tension and 67.5% in soil at the same tension. Further at 500 cm. tension only 1% of the total pore volume remains filled in sand whereas in soil as high as 31% of the total pore volume is filled with water. The total pore volumes at zero tension in soil and sand do not differ appreciably, but with increasing tension there is an increasing disparity between the percentage fractions of the total pore volumes which remain filled with water. This disparity is due to the fact that the pore size distribution in the two systems is not the same.

Pore size distribution: From the tension-water curves of soil and sand, the percentage fractions of the total pore volumes made up of pores between any two diameters can be taken and indicated against the pore size limits (Fig. 4). The pore size distribution against the pore volume is shown in the figure 4. In the soil nearly 60% of the total pore volume is made up of pores of diameter less than 0.02 mm. whereas in sand nearly 60% of the total pore volume is made up of pores of diameter between 0.2 mm. and 0.05 mm. In other words, major portion of the pore volume in soil is made up of fine pores and in sand of wide pores. This distinct difference in the pore size distribution in Delhi soil and Jumna sand is indicated in a very striking way in the pictorial diagram (Fig. 4).

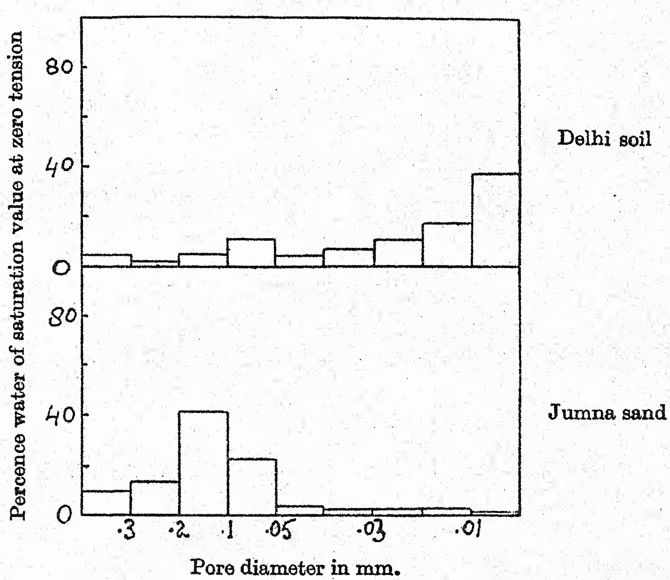


FIG. 4—Pore size distribution in Delhi soil and Jumna sand

pF-water relation: Baver (1938) has made an extensive study of the pF-water relation in a large number of soils and has drawn certain important generalizations. According to Baver, the amount of water withdrawn from zero tension to inflexion point represents the total non-capillary pore volume and that the permeability of a soil for water is directly proportional to this quantity and inversely proportional to the pF of inflexion point.

The pF-water relations in Delhi soil and Jumna sand have been indicated in Fig. 5. The positions of the inflexion points are also indicated in the curves. The amounts of water contained at zero tension and at inflexion point and the pF of inflexion points are shown in table 1. The weights of water per 100 cc. of soil and sand withdrawn from zero tension to inflexion point are 20.94 gm. and 19.72 gm. respectively. The pF values of inflexion points in the two systems are 2.15 and 1.36 respectively. Though there is no appreciable difference in the amounts of water withdrawn from zero tension to inflexion point, it is the marked difference in pF values of inflexion points that accounts for the difference in permeabilities of the two systems. The permeability coefficient for water of soil is 5.6 cm./hr. and for sand 143 cm./hr.

Permeability coefficient and porosity factor : According to Baver, the permeability of a soil is proportional to the porosity factor which is defined as the ratio of the amount of water withdrawn from zero tension to inflexion point and the pF of inflexion point. Porosity factors have been calculated for Delhi soil and Jumna sand and they are 9.74 and 14.50 respectively (table 1). For sand, both the permeability coefficient and the porosity factor are high and for soil, they are low. Porosity factor includes the combined effect of both the non-capillary pore volume and the pF of inflexion point.

SUMMARY

By employing the tensiometer technique, the tension-water and pF-water relations in Delhi soil and Jumna sand have been studied. From the tension-water relations, the pore size distributions in the soil and sand have been determined.

By employing the permeability technique, the permeability coefficients of soil and sand for water have been measured. The relation between permeability coefficient and porosity factor has been indicated.

Pore size distribution and the capacity for water at zero tension are different in Delhi soil and Jumna sand. In sand, the pores are all wider and in soil, they are finer. Correspondingly the permeability coefficient of sand is high and that of soil is low.

ACKNOWLEDGEMENT

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Effect of Compost Prepared with Superphosphate on Crop Yield

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Several workers have reported that the addition of humified organic matter like farmyard manure or compost along with superphosphate helps to minimise the fixation of the phosphate in insoluble forms in the soil (Swenson, Cole and Sieling, 1949 ; Struthers and Sieling, 1950) and shows better crop response than the application of phosphate alone to the soil (Copeland and Merckle, 1942 ; Midgley and Dunklee, 1945 ; Das, 1945 ; Aslander, 1950 ; Dalton, Russell and Sieling, 1952 ; Govinda Rajan, 1953). Part of the beneficial effect of compost plus phosphate mixtures in the above cases may be due to the nitrogen contained in the compost. Laboratory experiments carried out by the writers (unpublished data), however, confirmed the observations of previous workers that the fixation of superphosphate in insoluble forms in the soil could be minimised to a considerable extent by mixing the superphosphate with well-fermented compost. It would thus appear that a mixture of compost and superphosphate possesses several advantages over a straight application of superphosphate alone to the soil.

In order to verify the above relationships with reference to plant growth, two series of pot culture trials were carried out. In the first series, *marua* (*Eleucine coracana*) was grown as the test crop during the *kharif* season of 1953 and in the second series, berseem (*Trifolium alexandrinum*) was grown as the test crop during the *rabi* season of 1953-54.

Two methods of preparing compost plus superphosphate mixtures were tried. In one case, mixed cattle-shed wastes (dung, urine and litter mixed together) were first fermented for a period of four months and at the time of application to the soil, the compost was mixed with a defined dose of superphosphate. In the second case, the above dose of superphosphate was well mixed with the cattle-shed wastes before fermentation and the mixture was allowed to ferment for a period of four months and then applied to the soil. The experimental details are given below.

EXPERIMENTAL

Compost (A) prepared without the addition of superphosphate

500 lb. lots of mixed cattle-shed wastes (consisting of a mixture of cattle-dung, urine and litter) were fermented in cement-lined cisterns 3 ft. in length, 2 ft. in breadth and 3 ft. in depth. The refuse material was well mixed initially and samples were taken out for analysis. Since the mixed refuse contained a sufficiency of moisture (61.2%), no extra water was added. A temperature of 55°—60°C was attained in a week's time. At the end of two months' fermentation, the mass had shrunk down to a volume two-thirds of the original. It was then given a good turning in the cistern itself, along with the addition of 50 lbs. of water and allowed to ferment for a further period of two months. At the end of this period, the compost mass was taken out, thoroughly mixed, weighed and sampled for analysis.

Compost (B) prepared with the addition of superphosphate

The compost was prepared on similar lines to the above, but after placing each one-foot layer of the mixed refuse in the cistern, the mass was dusted with 2 lb. of super phosphate powder (total P_2O_5 17.22% and water-soluble P_2O_5 16.46%). Four similar

layers were similarly placed above and dusted with superphosphate. 500 lb. of mixed refuse and 8 lb. of superphosphate were added in all. In the present case also, the compost was given a good turning at the end of 2 months and after another 2 months' fermentation, the mass was taken out, well mixed, weighed and sampled for analysis.

The analytical data obtained with the two sets of composts are given in table 1.

TABLE 1

Analysis of refuse material and composts prepared

Particulars			Mixed refuse used for compost-making	Compost-A (without super-phosphate)	Compost-B (with supper-phosphate)
1.	Fresh weight ...	lb.	500	264	289
2.	Moisture ...	per cent	61.20	48.62	51.52
3.	Total dry matter ...	lb.	194.0	135.6	140.1
4.	Per cent carbon on dry matter		29.95	18.35	18.28
5.	—do— nitrogen —do— ...		1.106	1.420	1.450
6.	—do— P_2O_5 —do— ...		0.683	0.940	1.88
7.	Total quantity of carbon ...	lb.	58.12	24.88	25.61
8.	—do— nitrogen ...	lb.	2.146	1.925	2.032
9.	—do— P_2O_5 ...	lb.	1.325	1.275	2.634
10.	C/N ratio ...		27.09	12.92	12.61

The data show that the addition of superphosphate did not appreciably affect the nitrogen content of the resulting compost. This was possibly due to the fact that the original mixed refuse contained a sufficiency of phosphate to meet microbial requirements and for ensuring effective nitrogen conservation. A comparison of the total quantities of P_2O_5 contained in composts (A) and (B) shows that the difference, *viz*: 1.359 lb. P_2O_5 could be accounted for by the 8 lb. of superphosphate added to Compost (B), which contained 1.378 lb. total P_2O_5.

Pot experiments with marua (Eleucine coracana)—Kharif season 1953

The soil used was a sandy loam from the Indian Agricultural Research Institute experimental area and analysed as follows :—

TABLE 2

Analysis of soil

Mechanical analysis. (Per cent on oven-dry basis)		*Chemical analysis.* (Per cent on oven-dry basis)	
coarse sand ...	4.6	Total nitrogen ...	0.052
Fine sand ...	71.8	Total P_2O_5 ...	0.055
Silt	12.5	Available P_2O_5 (1% citric acid) ...	0.0055
Clay	10.3	CaO ...	0.588
pH 7.3		C/N ratio 9.42	

30 lb. lots of the soil were used for each pot and 5 pots were used for each of the following treatments :—(1) No manure ; (2) Compost-A (prepared without superphosphate addition) at 5 tons dry matter per acre ; (3) Superphosphate alone (equivalent to the P_2O_5 content of 5 tons of Compost-A ; (4) Compost-B (refuse and superphosphate fermented together) at 5 tons dry matter per acre ; and (5) Compost-A, (5 tons per acre) and superphosphate mixed at the time of application to the soil (total P_2O_5 equal to treatment 4).

The quantities of manures added to the pots under different treatments and the quantities of plant nutrients contained in them are shown in table 3.

TABLE 3

Manurial treatments

Treatment No.	Manure added per pot (30 lb. soil)	Total N added in manure (gm.)	Total P_2O_5 added in manure (gm.)
No. 1.	No. manure ...	nil	nil
No. 2.	76.2 gm. Compost-A ...	1.082	0.716
No. 3.	4.16 gm. Superphosphate ...	nil	0.716
No. 4.	76.2 gm. Compost-B ...	1.105	1.432
No. 5.	76.2 gm. Compost-A plus 4.16 gm. Superphosphate ...	1.082	1.432

Six plants of marua were grown in each pot and after four months growth, when the plants were ripe, they were harvested and the grain and straw were weighed separately and samples taken for analysis. The yield data for the different manurial treatments, are shown in table 4.

TABLE 4

Yield of marua (Eleucine coracana)

Average yield in gm. per pot (mean of 5 replicated pots)

Treatment	Grain (dry wt.)	Straw (dry wt.)	Total dry matter
1. No manure	7.4	23.8	31.2
2. Compost-A (5 tons dry matter per acre) ...	10.3	33.0	43.3
3. Superphosphate alone (P_2O_5 equal to treatment No. 2) ...	8.9	30.8	39.7
4. Compost-B (5 tons dry matter per acre) (refuse and super fermented together)	12.3	41.6	54.1
5. Compost-A plus super mixed at time of application to soil (total P_2O_5 and N equal to treatment No. 4) ...	10.3	32.6	42.9
Standard error	0.35	1.73	3.18

In table 4, treatments 2 and 3 contained the same quantity of total P_2O_5. The somewhat higher yields of grain and straw obtained in treatment 2 (Compost-A) as compared to treatment 3 (superphosphate alone) is presumably due to the additional effect of nitrogen contained in the compost manure. Treatments 4 and 5 contained equal levels of

nitrogen and phosphate and the higher yields obtained in treatment 4 is probably due to difference in availability of the superphosphate in the two treatments. In order to examine this point further, the plants grown under the different treatments were analyzed for their phosphate content and the total quantity of phosphate absorbed by them from the soil was calculated. The data are presented in table 5.

TABLE 5

Uptake of phosphate by marua (Eleucine coracana)

Average per pot (mean of 5 replicated pots)

Treatment	Percentage of P_2O_5 in dry matter		Total uptake of P_2O_5 (in grams)		
	Grain	Straw	Grain	Straw	Total
1. No manure	0.6365	0.1163	0.0471	0.0277	0.0748
2. Compost-A	0.6407	0.2630	0.0660	0.0864	0.1526
3. Superphosphate (P_2O_5 equal to treatment No. 2) ...	0.5967	0.2230	0.0531	0.0687	0.1218
4. Compost-B (refuse and super fermented together) ...	0.7310	0.3414	0.0899	0.1420	0.2320
5. Compost-A mixed with super at time of application (P_2O_5 & N equal to treatment No. 4) ...	0.7466	0.3028	0.0769	0.0987	0.1756
Standard Error	0.0184	0.0071	0.0022	0.0039	0.0052

The data show that :- (*a*) Along with an increase in the supply of phosphate to the soil (*cf.* treatments 4 and 5 against 1, 2 and 3) there is an increase in the percentage of P_2O_5 in both grain and straw, as well as an increase in the total quantity of P_2O_5 absorbed by the plant and stored in the above tissues. (*b*) Between treatments 2 and 3, which contain the same quantity of total P_2O_5, treatment 2 (Compost-A) shows a higher percentage of P_2O_5 in grain and straw, as well as a higher total absorption of P_2O_5 stored in the above tissues. (*c*). Between treatments 4 and 5, which contain equal quantities of nitrogen and phosphate, treatment 4 in which refuse plus superphosphate mixture was fermented before application to the soil, gives a higher total absorption of P_2O_5 in grain and straw, as compared to treatment 5 in which the refuse was fermented separately and the fermented product was mixed with superphosphate just at the time of application to the soil.

Pot experiments with berseem (Trifolium alexandrinum)

These were carried out in the *rabi* season of 1953-54 on lines similar to the experiments carried out with marua (*Eleucine coracana*) detailed above. Berseem was sown towards the end of October 1953 and the first cutting was taken when the plants were two months old. Succeeding cuttings were taken at monthly intervals. In all, 4 cuttings were taken. The weights of the cuttings obtained from the different treatments are shown in table 6.

TABLE 6

Weight of berseem cuttings (dry weight)

Average yield in gm. per pot (mean of 5 replicated pots)

Treatment	1st Cutting	2nd Cutting	3rd Cutting	4th Cutting	Total
1. No manure ...	0.6	1.2	4.5	2.1	8.4
2. Compost-A ...	2.1	6.4	12.4	5.3	26.2
3. Superphosphate (P_2O_5 equal to treatment No. 2) ...	1.7	1.3	14.5	6.0	23.5
4. Compost-B (refuse plus super fermented) ...	5.1	9.7	16.4	7.0	38.2
5. Compost-A mixed with super at the time of application to the soil (P_2O_5 & N equal to treatment No. 4) ...	2.6	5.8	15.7	5.9	30.0
Standard Error ...	0.09	0.79	0.51	0.39	1.15

The results obtained with berseem are similar to those obtained with marua, *viz* :—(*a*). Compost-A gives a higher yield of berseem cuttings than an equivalent quantity of super-phosphate, the difference being presumably due to the effect of nitrogen contained in the compost; (*b*) a mixture of refuse and superphosphate fermented together (treatment 4) gives a higher crop yield than the addition of superphosphate to the soil along with the compost fermented separately (treatment 5).

The cuttings were analysed for their content of P_2O_5 and the total uptake of phosphate by the berseem plants per pot was calculated. The results are presented in tables 7 and 8.

TABLE 7

Phosphate content of berseem cuttings

(Mean of 5 replicated pots)

Treatment	Percentage of P_2O_5 in dry matter			
	1st cutting	2nd cutting	3rd cutting	4th cutting
1. No manure ...	0.5499	0.6166	0.5356	0.3667
2. Compost-A ...	0.5429	0.6172	0.4822	0.5716
3. Superphosphate (P_2O_5 equal to treatment No. 2)	0.4942	0.6308	0.4882	0.5767
4. Compost-B (refuse plus super fermented together)	0.4941	0.4978	0.4805	0.6100
5. Compost-A mixed with super at time of application to soil (P_2O_5 & N equal to treatment No. 4) ...	0.5845	0.6017	0.5948	0.6016
Standard Error ...	0.0124	0.0156	0.0132	0.0164

TABLE 8

Uptake of phosphate by berseem

(Uptake per pot—mean of 5 replicated pots)

Treatment	Total P_2O_5 (in g.) in the cuttings per pot				
	1st cutting	2nd cutting	3rd cutting	4th cutting	Total cuttings
1. No manure ...	0.0033	0.0074	0.0241	0.0077	0.0425
2. Compost-A ...	0.0114	0.0395	0.0598	0.0303	0.1410
3. Superphosphate (P_2O_5 equal to treatment No. 2) ...	0.0084	0.0082	0.0708	0.0346	0.1220
4. Compost-B (refuse plus super fermented together) ...	0.0252	0.0483	0.0788	0.0427	0.1950
5. Compost-A mixed with super at time of application to soil (P_2O_5 & N equal to treatment No. 4) ...	0.0152	0.0349	0.0934	0.0355	0.1790
Standard Error ...	0.0006	0.0019	0.0036	0.0023	0.0068

The data show that the percentages of P_2O_5 in the dry matter of the cuttings (Table 7) do not show any consistent variation with the treatments, but the total quantity of P_2O_5 taken up by the plants (table 8) shows a definite increase with increasing quantities of phosphate added to the soil (*vide* treatments 4 and 5 as compared to treatments 1, 2 and 3). The difference between treatment 2 and 3 is, however, not significant in the case of berseem, while it was significant in the case of marua (vide table 5). This could be explained on the basis that since berseem is a legume, the nitrogen contained in the compost (treatment 2) has no marked effect in increasing the absorption of phosphate by the plant. It may also be noted that berseem is a heavier feeder on phosphate than marua and as such may be able to absorb phosphate equally from compost and superphosphate. The difference in the total quantity of phosphate absorbed in treatments 4 and 5 is also not significant.

DISCUSSION

The results of the two series of pot experiments show that the application of superphosphate alone to Delhi soil under examination gave a lower increase of crop yield than the application of compost manure containing the same quantity of phosphate. The difference could be explained as due to the effect of the nitrogen contained in the compost.

It was also observed that a preliminary fermentation of cattle-shed refuse plus superphosphate before application to the soil gave a higher crop yield than the application of superphosphate to the soil along with separately fermented refuse material. The superior effect of 'composted' superphosphate is explainable on the basis that the mixing of refuse and superphosphate before composting leads to a vigorous microbial development throughout the mass, as a result of which the superphosphate particles are brought into more intimate contact with the humus produced in the compost, than what is possible by a mechanical mixing of superphosphate with separately prepared compost material. Such fermented 'humus-superphosphate complexes' probably resist fixation by the soil minerals to form insoluble compounds and hence the phosphate is available for absorption by the plant to a greater extent than in a mechanical mixture of compost and superphosphate applied to the soil.

The present experiments were carried out on Delhi soil, which is moderately rich in total and available P_2O_4 (*vide* table 2). It is possible that the beneficial effect of 'composted' superphosphate may be seen still more clearly in soils low in available P_2O_5 and of high phosphate fixing capacity *e.g.* red and lateritic soils. Some trials carried out in Mysore (Govinda Rajan, 1953) showed that a mixture of farmyard manure and superphosphate gave higher crop yields than the application of superphosphate alone; but in the above experiments, the effect of a preliminary fermentation of cattle-shed refuse and superphosphate mixture was not examined. While carrying out such fermentation of cattle-shed refuse with superphosphate, it is of course necessary that sufficient available nitrogen in the form of cattle-urine or other sources is added, in order to promote rapid microbial action and abundant formation of active humus.

SUMMARY

Pot experiments carried out on a neutral sandy loam soil from Delhi, growing marua (*Eleucine coracana*) and berseem (*Trifolium alexandrinum*) showed that the application of compost manure gave higher crop yields than superphosphate containing an equivalent quantity of P_2O_5. The difference is attributed to the effect of nitrogen contained in the compost.

A mixture of cattle-shed wastes and superphosphate fermented for a period of 4 months, gave higher crop yields than the application of an equivalent amount of superphosphate to the soil along with an equivalent amount of compost fermented separately. The reasons for the superior manurial effect of such fermented mixtures of refuse and superphosphate are discussed.

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Improvement of Phosphate Availability in the Laterite Soils of the Nilgiris by the Application of Silico-phosphate

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"Silico-phosphate" or "silico-superphosphate" or "Serpentine superphosphate" are the names given to the fertiliser obtained by fusion of mixture of one part of ground serpentine (hydrated magnesium silicate) with three parts of freshly made superphosphate. Crowther and Lea (1946) in England, however, use the name "silico-phosphate" for their product obtained by sintering mineral phosphate, soda ash, and sand in the persence of steam at 1300 to 1400 °C. using powdered coal for fuel as in the ordinary cement manufacture. The fertiliser is, therefore, in essence made up of silica and phosphate. Birch (1948) Crowther and Lea (1946) have indicated from their experiments with this type of fertiliser that it is superior to commonly known phosphatic fertiliser like superphosphate, basic slag and rock phosphate for soils of the acid igneous group.

In the Nilgiris district of the Madras State, the soils are acidic and lateritic in nature. About 20,000 acres in this area are cultivated to potatoes. The analysis of a typical soil from this tract is given in table 1. Data presented in table 1 show that the soil has a high content of iron and aluminium oxide and a low content of lime with its pH on the acid side. Due to these factors, any soluble phosphate added to these soils gets immobilised and becomes unavailable to the plant. Consequently, a very high dose of available P_2O_5 in the form of superphosphate to supply 200 lb. of P_2O_5 per acre has been found to be necessary to keep up the good yields of potatoes in this tract and thus making the cost of manuring potatoes exhorbitantly high.

Table 1

Composition of the lateritic soil of Nanjanad (Nilgiris)

Constituents		
pH	4.3 to 5.0	
Moisture	4.37	per cent
Loss on ignition	12.11	,,
Insoluble mineral matter	52.63	,,
Iron (Fe_2O_3)	12.68	,,
Alumina (Al_2O_3)	15.59	,,
Lime (CaO)	0.056	,,
Magnesia (MgO)	0.106	,,
Total P_2O_5	0.150	,,
Total potash (K_2O)	0.453	,,
Na_2O	0.027	,,
SO_3	0.118	,,
CO_2	0.029	,,
Nitrogen	0.207	,,
Available P_2O_5	0.007	,,
Available K_2O	0.011	,,

The following correctives have been tried by other workers to prevent the reversion of phosphates in this type of soils: (1) Liming, (2) fertilizer placement, (3) pre-treatment of seed by soaking in a 5 per cent solution of K_2HPO_4 before sowing, and (4) application of organic matter. These correctives have had some partial effect (Birch 1948, Sanyasi Raju *et al.* 1954), but did not seem to hit the crux of the problem as the manure bill of the potato farmer would be increased and not decreased by all these further operations. In fact, even a high dose of lime at two tons per acre failed to shift the pH of the soil to any appreciable extent or to improve the yield (Sanyasi Raju *et al.* 1954).

There has been some indication in literature (Hall and Morrison, 1906; Toth, 1939; Lawes, 1951; Reifenberg and Buckwold, 1954) that silicates influence the assimilation of phosphorus. As mentioned earlier, since the application of silico-phosphate fertiliser was reported to be good in England (Crowther and Lea, 1946) for soils of the acid igneous group, it was proposed to study whether there was any beneficial effect of this fertiliser on the acid soils of the Nilgiris and, if so, whether silica had any part to play in inducing the beneficial effect. Hence sodium silcate and silico-phosphate were tried separately on potted soils from the Nilgiris in comparison with the regular superphosphate usually applied by the potato growers of Nilgiris.

MATERIAL AND METHODS

The material for the present investigation consisted of a well mixed sample of surface soil from the Agricultural Research Station at Nanjanad in the Nilgiris. The soil was sampled out into sixteen glazed pots and given the treatment as given in table 2.

TABLE 2

Plan of the experiment

Treatment	Soil alone	Soil+Lime (lime at 3000 lb. per acre)	Soil+green manure (green manure at 7500 lb. per acre)	Soil+Lime+green manure
No treatment ...	Pot No. 1	Pot No. 5	Pot No. 9	Pot No. 13
Sodium silicate at 1000 lb. per acre ...	,, 2	,, 6	,, 10	,, 14
Superphosphate at 180 lb. of available P_2O_5 per acre ...	,, 3	,, 7	,, 11	,, 15
Silico-phosphate at 180 lb. of available P_2O_5 per acre ...	,, 4	,, 8	,, 12	,, 16

The treatments were so laid out as to bring out (1) the effect of sodium silicate, (2) the effect of silico-phosphate, (3) the effect of lime, and (4) the effect of organic matter and combinations of these. The soil was maintained throughout the experiment at a moisture level of 50 per cent of its water holding capacity. The dosages of fertilisers and amendments were calculated per acre to tillage depth, *viz.*, 9 inches. Green manure and lime additions were based on optimum dosages of 3000 lb. of lime and 7500 lb. of green manure arrived at for the leterite soils of Pattambi in Malabar from the trials conducted from 1950 to 1952 (unpublished data of the chemistry section, Agricultural Research Institute, Coimbatore). The superphosphate used in the experiment was ordinary "super" containing 18.71 percent water soluble P_2O_5. Fresh leaves of *Gliricidia maculat* were used for green manure. As no commercial sample of silico-phosphate was available in the

market, a mixture of calcium phosphate, sodium silicate and magnesium oxide in the proportion of 10 : 3 : 3 was sintered at 1150 degrees centigrade in an electric oven and utilized for the experiment as "silico-phosphate." This had a citrate-soluble P_2O_5 of 13.03 percent.

The potted soil used in the experiment was analysed for available P_2O_5 initially and immediately after treatment and also subsequently every fortnight for a period of 2 months. The analysis for available P_2O_5 was done in the air dry soil by Troug's colometric method (Troug and Meyer, 1929 ; Mariakulandai and Venkatachalam, 1954) using Spekker's absorptiometer for assessment of the colour developed. Moisture was also estimated and the available P_2O_5 content expressed on oven dry basis. The pH of the soils were also noted.

To evaluate by plant response the nutrient status under the different treatments, a modified Neubauer's test (Neubauer and Schneider, 1923) was conducted with ragi (*Eleucine Corocana*) at the end of the two months of experimentation. Equal number of ragi seeds were sown in the differently treated pots and grown under standard green house conditions for a period of 18 days and the seedlings analysed for phosphorous uptake. The growth of the seedlings under the different treatments were also photographed. The height and dry weight of the seedlings were also noted.

RESULTS AND DISCUSSION

(*a*) *Available P_2O_5 by analysis :* The results of the periodic analysis for available P_2O_5 in sixteen treated soils are presented in table 3 along with the pH of the soils after the treatment.

TABLE 3

Available P_2O_5 in soils drawn from the silico-phosphate studies (Expressed as mg./100 g. of soil)

Treatments	Available P_2O_5 in soils drawn on					pH
	19.1.54	1.2.54	17.2.54	5.3.54	22.3.54	
I. *Control series*						
1. Control	5.54	7.16	7.46	7.41	6.88	5.75
2. Sodium silicate	6.77	6.97	6.33	6.49	6.47	5.25
3. Superphosphate	7.41	9.67	7.88	8.04	8.14	5.55
4. Silico phosphate	15.45	14.38	13.75	14.02	12.60	5.55
II. *Lime series*						
5. Control Lime	7.60	8.33	7.14	7.41	7.60	5.40
6. Lime+sodium silicate	5.20	7.78	7.45	6.29	6.04	5.55
7. Lime+superphosphate	6.03	9.47	9.12	7.91	7.61	5.55
8. Lime+silico-phosphate	18.69	13.52	13.89	13.87	12.83	5.60
III. *Green manure series*						
9. Green mature	6.56	6.23	6.75	6.48	6.87	5.55
10. „ + sodium silicate	6.75	6.33	7.37	6.69	6.36	5.35
11. „ + superphosphate	9.34	9.86	8.51	6.96	7.60	5.25
12. „ + silico-phosphate	13.19	21.48	12.77	12.26	11.35	5.35
IV. *Lime+Green manure series*						
13. Lime + green manure	6.95	6.75	6.96	6.18	6.35	5.55
14. „ + „ + sodium silicate	7.37	6.75	7.15	6.49	7.52	5.60
15. „ + „ + superphosphate	8.99	11.10	9.23	7.31	8.98	5.60
16. „ + „ + silico-phosphate	13.17	15.16	15.45	13.40	12.40	5.65

The results show that (1) by silico-phosphate application the phosphoric acid available to the plant after incorporation of the fertiliser into the soil was nearly double that obtained by addition of superphosphate at the same P_2O_5 level. (2) The soluble P_2O_5 in superphosphate which was added at the same rate of 180 lbs. available P_2O_5 per acre as in the case of silico-phosphate got immobilised immediately on addition and was not available to the plant. (3) This immobilisation of the available P_2O_5 took place immediately on application and continued to be at the same level throughout the period of experimentation. (4) Application of sodium silicate did not affect the available P_2O_5. (5) Lime and green manure did not materially alter the available P_2O_5 nor even the pH of the soil.

(*b*) *Available P_2O_5 as adjudged by plant growth response :* The growth response as adjudged by (1) the height of the plant, (2) total dry weight of the plant, (3) the total ash weight of the plant, and (4) the net phosphorus uptake of the plant at the end of 18 days of growth of ragi in pots under standard green house conditions. The data are presented in table 4.

TABLE 4

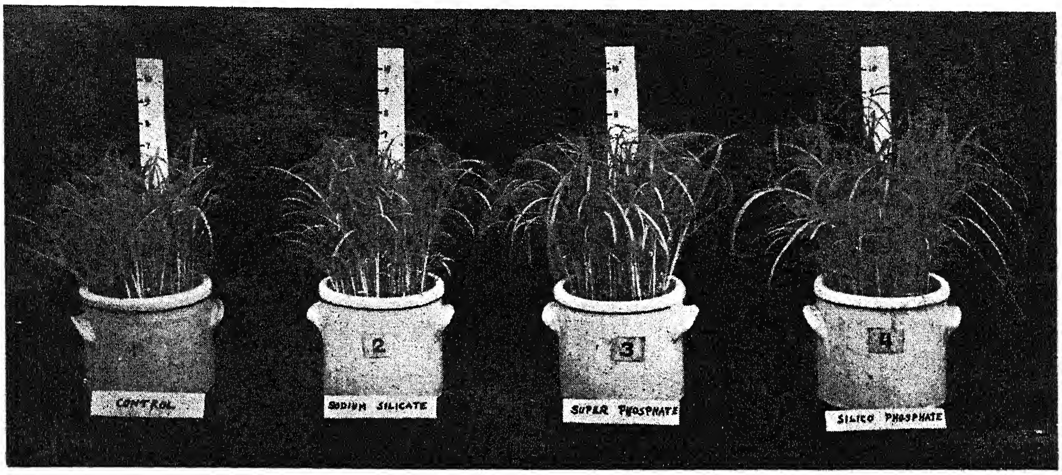
Growth response and phosphorus uptake of ragi seedlings of 18 days growth

	Maximum height (cm.)	Total dry weight in grammes (dried at 100°C)	Total ash (gm.)	Total uptake of P_2O_5 (mg.)
Series I—Control series				
1. Control ...	25.5	2.40	0.43	14.37
2. Sodium silicate ...	27.0	3.07	0.54	17.75
3. Superphosphate ...	31.0	2.84	0.46	18.12
4. Silico-phosphate ...	46.0	3.71	0.61	34.74
Series II—Lime series				
5. Lime ...	20.0	1.52	0.30	10.13
6. ,, + sodium slicate ...	29.0	2.86	0.51	24.00
7. ,, + superphosphate ...	31.0	2.79	0.51	22.13
8. ,, + silico-phosphate ...	34.0	2.86	0.57	24.37
Series III—Green manure series				
9. Green manure ...	22.0	1.36	0.25	11.50
10. ,, + sodium silicate ...	27.0	2.34	0.41	21.75
11. ,, + superphospate ...	25.0	1.62	0.33	15.75
12. ,, + silico-phosphate ...	34.5	3.03	0.60	29.25
Series IV—Lime and green manure				
13. Green manure and lime ...	26.0	1.97	0.37	17.87
14. ,, + ,, + sodium silicate	24.0	1.88	0.38	11.75
15. ,, + ,, + superphosphate	30.0	2.88	0.56	23.25
16. ,, + ,, +silico-phosphate	35.0	3.15	0.64	28.25

The photographs of the *ragi* plants at the end of 18 days of growth are presented in figure 1 showing the growth response under the 16 different treatments.

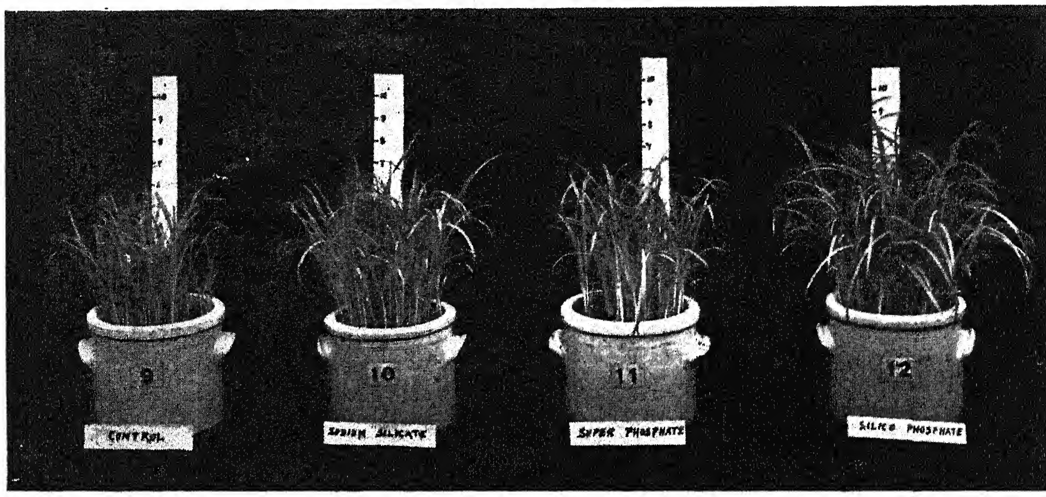
Silico-phosphate treated pots record the best growth response as compared to the other treatments. Sodium silicate induces a slightly better growth response than the

PLATE I—GROWTH RESPONSE OF RAGI SEEDLINGS

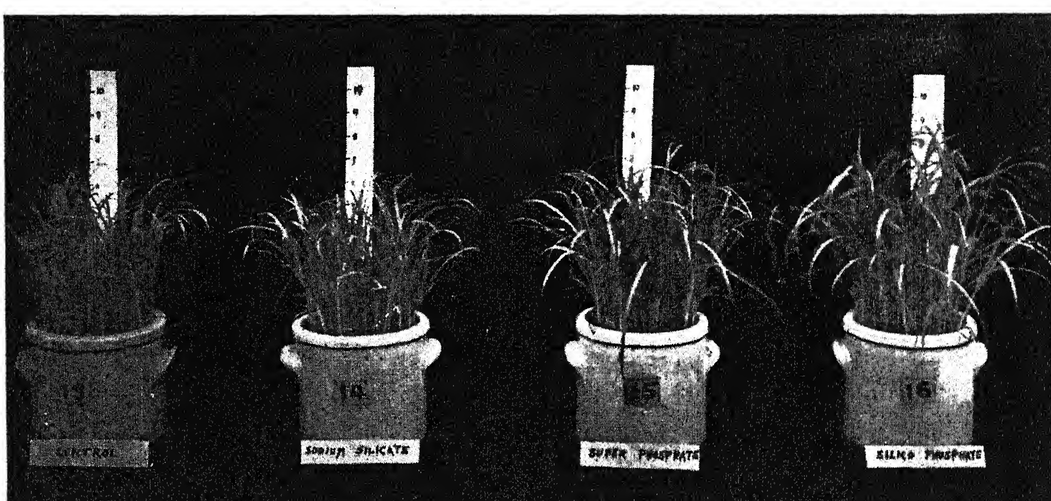


SERIES I—Control Series

SERIES II—Lime Series



SERIES III—Green Manure Series



SERIES IV—Lime and Green manure Series

control, but, is not as good as superphosphate or silico-phosphate treated pots. The treatments in the descending order of merit are as follows: (*a*) silico-phosphate, (*b*) superphosphate and (*c*) sodium silicate.

Lime, either by itself or together with organic matter, is able to improve the growth as also the phosphate uptake by the ragi plant in only the superphosphate treated pots. Organic matter by itself, is not able to influence either the growth or the phosphorus uptake of the plants.

Silicon as sodium silicate has given a slight response in growth but not to the extent that phosphate fertilisers have given in this study. Hence, as contended by Scarseth (1935), complete substitution of the phosphatic fertiliser by silicon is contra-indicated by this study on the laterite soils of Nanjanad. The role of soluble silica in the release of the orthophosphate ion has been discussed by Reifenberg and Buckwold (1954). The silica release reaction was said to be affected by the phosphate concentration, the solution: soil ratio and time, while neutral silicate in solution was similarly able to release the fixed phosphate from the soil. It is to this property of soluble silicates that its benefit to soil fertility is attributed. But in the present experiment, the addition of soluble silicate did not reveal any benefit to the available P_2O_5 though it recorded a slightly better growth test over the control. The best effect was seen only when straight silico-phosphate was used.

In the laterite soils of the Nilgiris where it has, time and again, been noticed that any added soluble phosphate becomes rapidly immobilised and not available to plants this effect of the silico-phosphate fertiliser in increasing the phosphate availability is a welcome solution to the age old problem of reducing the manure bill of the potato farmer.

The correctives like lime and organic matter used in this experiment, though tried at doses found beneficial in a similar laterite soil of Pattambi of south Malabar, failed to benefit the soil of the Nilgiris. Nor could it change the pH. This is in conformity with our experience since 1935 with the soils of Nilgiris when one to two cwt. doses of liming had been tried with no effect on the yield or pH of the soils at the Agricultural Research station, Nanjanad. So, in 1950-52 a heavy dose of 2 tons of lime per acre (Sanyasi Raju, Varadarajan and Kunjamma, 1954) was tried. Even this uneconomic dose of 2 tons of lime per acre failed to affect the pH or the yield. Hence it was thought best to look into other avenues for solving the problem of phosphate fixation in the Nilgiri soils. This preliminary investigation reveals that silico-phosphate hits the crux of this problem (1) by bestowing phosphorus in a form which cannot be immobilised by the free iron and alumina of these lateritic soils and (2) by reducing the farm operation to a single manurial commitment, thus reducing the manurial bill considerably.

SUMMARY

This article embodies the results of a preliminary investigation undertaken to study the effect of soluble silica on the release of phosphates and the possible utilization of the effect in the solution of the age-old problem of immobilised phosphates in the lateritic soils of the Nilgiris, South India. This investigation had as its ultimate object the reduction of the manure bill of the Potato grower in the Nilgiris, who had to apply nearly 200 lb. of P_2O_5 per acre as against the 23 lb. of P_2O_5 which the potato crop removed per acre. The P_2O_5 added was fixed by the free iron and alumina sesquioxides present in high amounts in these lateritic soils and very little of the applied P_2O_5 was actually available to the potato plant.

With this objective, typical lateritic soil was obtained from the Agricultural Research station, Nanjanad in Nilgiris and treated in 16 different glazed pots with silico-phosphate, superphosphate, sodium silicate, lime and green manure, so as to bring out (1) the effect of sodium silicate, (2) the effect of "silico-phosphate"—a fertiliser containing soluble silicate, and P_2O_5, (3) The effect of lime, and (4) the effect of green manure.

Available P_2O_5 in soil was analysed by Troug's method periodically for two months in the different treatments. Plant growth response and uptake of phosphorus were noted at the end of 2 months using *Ragi* as test plant and the results of the experiment indicate the following important points:

(*a*) Soluble silicate by itself was able to induce some slight growth response and phosphorus uptake over the control but was not as good as the "superphosphate or silico-phosphate" treated pots.

(*b*) The treatments in the descending order of merit were as follows: (*i*) Silico-phosphate, (*ii*) Superphosphate and (*iii*) Sodium silicate.

(*c*) The soluble P_2O_5 in the superphosphate got immobilised immediately on addition to the soil and was not available to the plant, but lime was able to correct this to some extent and give a better growth and phosphorus uptake while organic matter did not materially affect the trend of results in this direction.

(*d*) The silico-phosphate by itself was able to give the highest available P_2O_5 in contact with the soil and yield the best growth and phosphorus uptake in plants. Lime and organic matter did not affect the phosphate availability either for or against, when silico-phosphate was added.

Silico-phosphate, therefore, seemed to be the best phosphatic manure suitable for the lateritic soils of the Nilgiris requiring neither lime nor organic matter as correctives as in the case of superphosphate treated soils.

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Changes in Soil Associated with the Growth of Cactus (*Opuntia dilleni*)

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Roots of plants have been known to be responsible, to some extent, for disintregation of rocks which form the parent material of soils developed on them. The extreme economy of moisture by *Opuntia* and the adoptability of its root system to different soil conditions have been worked out in detail by Cannon (1918; 1925). The root system of thorny plants like *Opuntia* has been ascribed by Khan (1932) to be responsible for formation of loose sandstones from granite and trap rocks. It is not known, if the reported fertility of soils, freshly reclaimed from wild growth of *Opuntia* on poor gravelly soil is due to greater weathering of soils under the cactus than that under common cultivated crops with less intensive root system. It was considered worthwhile to make a study of the changes brought about in ordinary soils by the growth of cactus. During the present investigation, physical and chemical properties of soils from four different places each having soil under cactus and soil without vegetation adjoining the former in an uncultivated area, were determined. It was expected that the results of determinations would throw light on the precise changes brought about by the growth of cactus in the soil.

MATERIALS AND METHODS

The soils of the region where the localities had been chosen for collection of soil samples, are alluvial mixed with gravel in different proportions and the sieved soils are generally loams. They are slightly alkaline in nature. Inspite of their sandy nature, they develop high degree of stickiness when moistened with water. In summer the fields develop large cracks with compact blocks of soil between the cracks. It has been a general observation that soils of the areas, where cactus has been growing wild for a number of years, are generally loose and friable and working the soils with mechanical impliments is quite easy.

Two surface soils (0—1 ft.) from each locality were collected. One was under cactus and the other without any vegetation in the immediate neighbourhood. The soils were obtained from four localities.

Percolation rate was determined by packing as uniformly as possible, 10 c.c. of soil in a 50 c.c. burette, the bottom of which was filled with cotton wool. 40 c.c. of water were added and the volume of percolate in an hour was noted. It was evident that by this method only approximate and comparative figures were obtained. Chemical and mechanical constituents were determined by the usual methods (Piper, 1942).

RESULTS AND DISCUSSION

The detailed results of the determinations of chemical and physical constituents of soils under cactus and no cactus are given in table 1.

TABLE 1

A. *Mechanical composition of the soils*

(Expressed as per cent on oven dry basis)

Locality	Description of the soil	Sands	Silt	Clay
1	Without cactus	59.89	19.71	20.40
	With cactus	76.48	12.60	10.92
2	Without cactus	65.98	20.85	13.17
	With cactus	66.52	26.82	6.66
3	Without cactus	68.35	17.25	14.40
	With cactus	74.95	14.82	10.23
4	Without cactus	65.83	24.57	9.60
	With cactus	72.52	21.00	6.48

B. *Chemical composition of the soils*

(Expressed as per cent on oven dry basis)

Locality	Description of the soil	Organic carbon	Organic nitrogen	Total b.e.c. (m.e.)	Exch. Ca (m.e.)	pH	Total soluable salts (mg.)
1	Without cactus ...	0.91	0.065	8.05	3.25	8.2	72.9
	With cactus ...	0.87	0.079	4.55	1.25	7.8	105.6
2	Without cactus ...	0.87	0.061	7.60	3.50	8.0	127.4
	With cactus ...	1.04	0.094	4.20	2.25	7.4	165.1
3	Without cactus ...	1.39	0.089	6.43	3.75	8.1	73.2
	With cactus ...	1.08	0.099	5.42	4.00	7.4	132.9
4	Without cactus ...	1.29	0.092	6.75	4.25	8.0	113.6
	With cactus ...	1.80	0.114	4.94	3.25	7.6	153.8

C. *Soluble constituents of the soils*

(Expressed as mg. per cent on oven dry basis)

Locality	Description of the soil	HCO_3	Cl	SO_4	Ca	Mg	K	Na
1	Without cactus ...	36.6	5.3	6.7	15.0	1.2	1.2	6.6
	With cactus ...	61.8	3.5	5.1	20.0	1.2	1.2	12.6
2	Without cactus ...	67.1	8.8	9.0	20.0	1.2	0.4	20.9
	With cactus ...	91.5	7.0	10.9	20.0	3.0	0.4	32.3
3	Without cactus ...	36.6	2.6	9.6	15.0	1.5	0.4	7.5
	With cactus ...	73.2	3.5	11.9	25.0	1.2	0.4	17.7
4	Without cactus ...	64.1	2.6	9.0	25.0	1·2	0.4	11.3
	With cactus ...	91.5	4.4	6.6	30.0	1.0	0.4	11.9

D. *Silica-alumina and silica-sesquioxide ratios of clay obtained from the soils*

Locality	Description of the soil	SiO_2/Al_2O_3	$SiO_2/Al_2O_3+Fe_2O_3$
1	Without cactus	3.69	3.20
	With cactus	5.78	4.95
2	Without cactus	4.91	4.29
	With cactus	5.55	4.83
3	Without cactus	3.50	2.89
	With cactus	3.50	3.00
4	Without cactus	3.96	3.37
	With cactus	4.62	3.75

E. *Rates of percolation through the soils* (average of two determinations)

(Expressed in c.c. per hour)

Locality	Description of the soil	Percolation rate
1	Without cactus	29
	With cactus	35
2	Without cactus	27
	With cactus	29
3	Without cactus	6
	With cactus	17
4	Without cactus	15
	With cactus	28

In table 2 are given the mean values of different constituents of the soils, bare and under cactus, along with their standard errors.

TABLE 2

Composition of the bare soils and adjoining soils under cactus at the surface

(Constituents expressed as per cent on oven dry basis)

Constituent	No cactus (a)	Under cactus (b)	Difference (a—b)=d	$\pm SE_d$	t
Mechanical composition					
Sands	65.01	72.62	—7.61	3.32	2.29
Silt	20.60	18.81	1.79	2.77	0.64
Clay	14.39	8.57	5.82*	1.41	4.13
Chemical composition					
Organic carbon ...	1.11	1.20	—0.09	0.07	0.49
Organic nitrogen ...	0.078	0.095	—0.017*	0.0048	3.66
Total exchange capacity (m.e.) ...	7.21	4.78	2.43*	0.61	3.97
Exchangeable Ca (m.e.) ...	3.69	2.69	1.00	0.47	2.14
pH ...	8.08	7.65	0.43**	0.063	6.76
Total soluble salts (mg.) ...	96.78	139.08	—42.30**	6.00	7.05
Soluble constituents					
HCO_3 (mg.) ...	51.10	79.50	—28.50**	2.81	10.12
Cl (mg.) ...	4.83	4.60	0.23	0.93	0.24
SO_4 (mg.) ...	8.58	8.63	—0.05	1.20	0.04
Ca (mg.) ...	18.75	23.75	—5.00	2.04	2.45
Mg (mg.) ...	1.28	1.60	—0.32	0.50	0.66
K (mg.) ...	0.60	0.60	0.00	0.00	0.00
Na (mg.) ...	11.58	18.63	—7.05	2.44	2.89
Composition of the clay					
SiO_2/Al_2O_3 ...	4.02	4.86	—0.84	0.44	1.92
$SiO_2/(Al_2O_3+Fe_2O_3)$ ...	3.44	4.13	—0.69	0.36	1.92
Percolation rate					
Percolation rate (cc./hour) ...	19.25	27.25	—8.00*	2.48	3.22

* Significant at 5 per cent. (Theo. value of t=3.18)

** Significant at 1 per cent. (Theo. value of t=5.84)

It is clear from the data in table 2 that the amount of clay in the soil under cactus is significantly less than what is contained in the bare soils. This may be due to loosening of the soil aggregates by the intensive root system of the cactus and subsequent loss by transport of the clay from the root zones to other places. As the surface soils only were examined, it cannot be said with certainty if this movement of clay takes place to lower depths of the soil. The lower clay content of the soil under cactus may also explain the significantly higher percolation rates and the significantly lower base exchange capacity of these soils as compared with the ones without cactus.

While the difference in the organic matter content of the soils under no vegetation and those under cactus is not significant, the soils under cactus contain significantly higher amounts of nitrogen than the soils without them. It may mean that while the organic matter content of the soils is not expected to increase under cactus growth, the nitrogen content increases under it. It may be due to nitrogenous excretions from the roots of the cactus. This has yet to be confirmed. The difference in the pH values of the soils under cactus and under no vegetation is highly significant. The lower pH in the soils under cactus may be explained by respiration of the intensive root system (Lundegårdh, 1924) which, in the case of the cactus may be appreciable (Weaver, 1926). The increased salinity in the soils under cactus may be due to the same causes as carbon dioxide is known to have remarkable solvent action on soil minerals (Stewart and Martin, 1921; Metzgar, 1927).

The difference in the bicarbonate contents of the two groups of soils has been found to be highly significant and the fact that the soils under cactus have higher bicarbonate content than the soils without vegetation indicate that the soil mineral have come to solution mainly through the agency of carbon dioxide respired by the roots.

The differences in the other constituents of the two groups of soils have not been found to be significant. It is felt that some of them might have come to light, had soils of a large number of localities been examined during the course of the investigation.

SUMMARY

From a study of the composition of the surface soils from four different localities growing cactus and of surface soils without vegetation lying adjacent to them, it has been observed that

(1) growth of cactus in soils is associated with significant loss of clay probably by loosening of soil aggregates by the intensive root system. It does not affect any change in the organic matter content of the soils but increases significantly the nitrogent content, and

(2) growth of cactus induces lowering of base exchange capacity and pH of the soils and is associated with increase in salinity. That this increase in salinity in soils under cactus is due to solvent action, on soil minerals, of carbon dioxide respired by the roots is evident from the significant increase in the bicarbonate content of the soils under cactus.

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Loss of Nitrogen in the Form of Ammonia from Water Logged Paddy Soil

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West Bengal is pushing ahead the consumption of ammunium sulphate for intensive food production drive involving worth over a crore of rupees. Some knowledge regarding its optimum dose, effect on the type of soil and crops have already been obtained. Pearshall (1950) reports that hardly 30 per cent of the added nitrogen is utilised by the crop. The fate of the rest of 70 per cent of nitrogen is unknown. Recent studies by De and Digar (1954) have indicated that at least some of the added nitrogen may be lost in the form of elemental nitrogen from water logged soils. For fertilisers containing or yielding ammonia, when incorporated into the soil, either with irrigation water or by broadcasting followed by irrigation, the greater portion of ammonia gets absorbed on the soil surface (Jewitt, 1942). Evidences are there, that varying portion of nitrogen from the ammonium sulphate or nitrogenous fertilisers applied to the soil is lost in the form of ammonia. This depends upon the amount of water present over the soil. (Wills and Sturgis, 1945), pH and content of calcium carbonate (Steenbjerg, 1947). Soil reaction is an influencing factor (Martin & Chapman, 1951). The greater is the alkalinity of the soil, the larger is the loss of ammonia from it. This type of losses increases with an increase of temperature.

Some of the soil tracts of West Bengal have pH above 7.0. Since the main fertilisers used for intensive food production are in the form of ammonium sulphate or nitrogenous manures which will produce ammonia upon decomposition in the soil, it was necessary to obtain some information on possible magnitude of losses of nitrogen in the cropping practice generally followed. Both the upland and lowland paddy, locally known as *Aus* and *Aman*, are grown in West Bengal. In the *Aus* paddy fields, water logging does not take place. But *Aman* paddy is always grown in standing water varying in depth from 2 to 3 inches. The maximum consumption of fertilisers takes place in the areas where *Aman* is grown.

MATERIAL AND METHOD

Soil samples (0-8 inches) from the Police Station Domkal, of the District of Murshidabad was taken for investigation. This had a pH 8.4, calcium oxide—3.4 percent, silt—22.3 per cent and clay—14.0 per cent. The soil under experiment was collected from a cultivator's field, growing *Aman*—fallow—*Aman* from the first layer of the soil.

The experimental unit (Fig. 1), devised for this purpose, was as follows. A 10.0 litre aspirator bottle provided with delivery tube fitted at the bottom and a rubber stopper, carrying two glass tubes, were fitted to the mouth of the aspirator bottle. One of these tubes projected about 3 inches below the rubber stopper, but did not touch the soil or water in the aspirator bottle. The outer portion of this tube was bent at right angles, which was connected to a gas washing bottle cotaining sulphuric acid and glass beads to absorb every trace of ammonia from the incomming air. During the course of the experiment, a slow but continuous stream of air was drawn through the aspirator bottle and absorption towers. The other tube of the aspirator bottle was connected to a gas washing tower containing standard sulphuric acid and glass beads, the other end of the gas washing tower

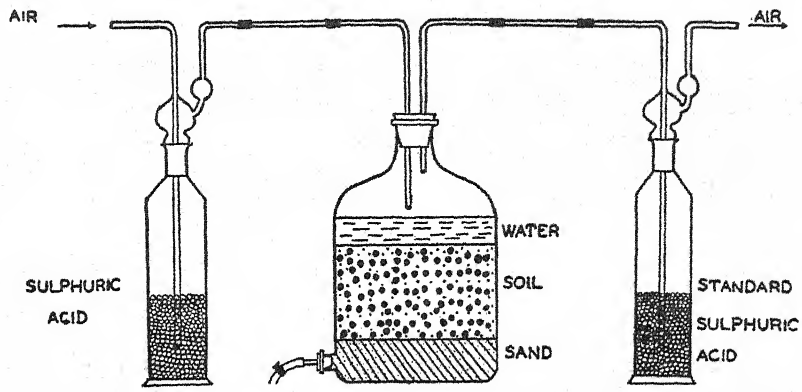

FIG. 1—Experimental unit for measuring the loss of ammonia from soil

was connected to a filter pump which was worked slowly as shown in the Fig. 1. During the course of investigation, a slow stream of air was continuously drawn through the aspirator bottle. Thus the ammonia volatilized was absorbed in the second tower containing standard sulphuric acid.

The aspirator bottles were first charged with a layer of coarse sand (4 inches) and then with soil and water. It was allowed to stand until the soil had settled, after which the supernatant water was slowly drained through the delivery tube below, and a depth of 2 inches of water was maintained on the surface of the soil. In all, 6 kilograms of soil were used in each aspirator bottle. The aspirator bottles were wrapped with black paper up to the height occupied by the soil, so as to expose only the surface of the soil and water to sunlight. The aspirator bottles were placed outside laboratory in open air. The condition at which the experiments were conducted resembled the condition occuring in the *Aman* paddy fields. Ammonium sulphate (0.18 g. of nitrogen added per bottle) corresponding to 60 lb. of nitrogen per acre was added on the surface of the treated soils, and air was continously drawn through the aspirator bottles and through the absorption towers. The ammount of ammonia volatilized was determined by back titration against standard alkali after 24 hr. intervals. This was continued up to 15th day. A blank was continuously run side by side for each set of experiment. The tests were run in duplicate and were repeated. The mean average temperature for each day was also recorded.

RESULTS AND DISCUSSION

The amount of nitrogen volatilized as ammonia from Domkal surface soil under water-logged condition after the application of ammunium sulphate at 60 lb. of nitrogen per acre is recorded in table 1.

In the preliminary investigation conducted with the same soil, it was found that the amount of ammonia volatilized was greatly influenced by the temperature of the soil. At the same concentration of ammonium sulphate on the surface soil, there was more loss due to volatilization when temperature recorded was high than when the temperature was low. This confirms the observation of Martin and Chapman (1951). This may be due to the fact that the amount of nitrogen volatilized as ammonia is governed by the rate of evaporation of water from the soil surface.

TABLE 1

Mg. of nitrogen volatilized as ammonia per day

Days	Amount of N volatilized as ammonia (mg.)	Percent of the added N volatilized	Mean temperature per day in °F
1	6.55	3.64	91
2	5.43	3.02	90
3	7.00	4.00	89
4	1.84	1.03	94
5	1.05	0.58	91
6	2.80	1.55	92
7	3.33	1.85	92
8	3.00	1.66	90
9	2.91	1.61	85
10	1.00	0.66	87
11	1.07	0.59	88
12	1.00	0.55	90
13	0.73	0.40	89
14	0.70	0.32	88
15	0.70	0.32	86
Total	39.51	21.78	

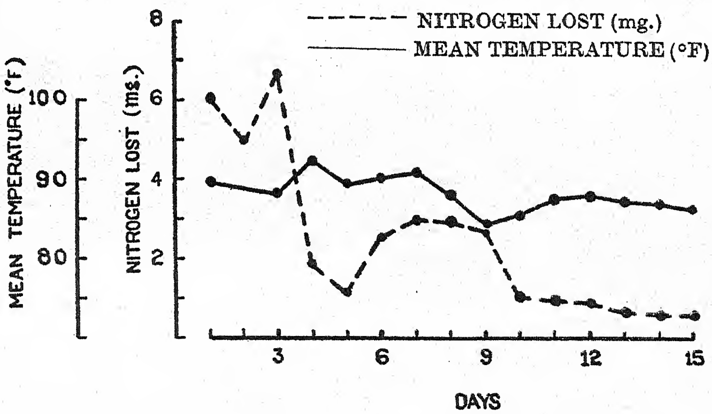

FIG. 2—Loss of nitrogen as ammonia and variation of temperature

Results (table 1 and Fig. 2) show that the losses were quite heavy during the first three days of investigation. Then, there was a sharp fall on the fourth day which continued up to fifth day. From the sixth day there was a steady rise as indicated in the graph indicating steady losses due to volatilization which continued up to seventh day. Then there was a fall in the graph indicating less losses, which continued up to the end of the experiment. The experiments were discontinued on the 15th day as loss recorded beyond 16th day was negligible.

Out of the 21.78 percent of the added nitrogen found lost in 15 days, a loss of more than 10 percent of the added nitrogen occured in the first three days. The rest of the loss

by volatilization occured in the next 12 days of investigation. Steenbjerg (1947) reported 60 percent loss from soil fertilized with ammonium sulphate at pH 8.0 in four weeks. Daji (1934) working at Woburn found that up to 40 percent of nitrogen of young mustard or tare plant was lost from the soil in two months.

The possible magnitude of losses of ammonia from application of ammonium sulphate in alkaline soil under growing condition of paddy and probable means to minimize this loss are under investigation and will be communicated in the next part of the paper.

SUMMARY

The investigation showed that when alkaline soil was treated with ammonium sulphate, a large amount of nitrogen was lost as ammonia. This loss began immediately after the application of fertiliser and continued even after 15 days. In first few days, the loss was maximum. If fertilizers like ammonium sulphate are applied as top dressing to alkaline rice field, there will be losses due to volatilization of ammonia.

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Influence of Fertilizers and Manures on the Content of Phytin and Other Forms of Phosphorus in Wheat and Their Relation to Soil Phosphorus

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Phosphorus occupies a dominating position in the metabolism of plants. Study of different forms in which this element exists in plants and their possible changes under the influence of environmental or other external factors has drawn considerable attention during recent years. Some information of general nature is available on the uptake of phosphorus by plants under the influence of fertilizers and manures, specially the phosphatic fertilizers. Barring a few scattered references, no systematic study is on record regarding the influence of environmental conditions on the different forms of phosphorus in cereal grains. In view of the recent trend in the use of large quantity of phosphatic fertilizers in increasing the yield of food grains, it was considered of interest, both from the practical and academic points of view, to elicit such information with wheat as the test crop. Permanent Manurial Experiments at Pusa, (Bihar) provided an excellent opportunity for this purpose. The objectives of the present investigation were to study the variation in the content of phytin and other forms of phosphorus in wheat grains as influenced by phosphatic and other fertilizers and also to study any changes in these constituents that might have taken place in relation to soil phosphorus.

MATERIALS AND METHODS

The material consisted of eighteen samples of wheat grown in each of the eighteen plots ($\frac{1}{4}$ acre each) under different manurial and cultural conditions in the Permanent Manurial and Rotational Experiment at Pusa, Bihar. These experiments are being carried out since 1908 to study the effect of manures, fertilizers and also the effects of rotation with and without green manures in the maintenance of soil fertility. The details are given in table 1. Soil samples were collected from each of the corresponding plots by the conventional methods of sampling.

Wheat grains were sampled by the method recommended by the Association of Official Agricultural Chemists (1940) and followed in this laboratory (Das *et al.* 1954). Total phosphorus was estimated by the colorimetric stannous chloride method (Dickman and Bray, 1940) in the wet digest of an aliquot of wheat (Piper, 1947). Phytin was extracted by the method of McCance and Widdowson (1935) and phosphorus in it determined as before. Inorganic and acid-soluble phosphorus were determined by the method described by Pons *et al.* (1953).

Total phosphorus in the soils were determined by Pemberton's volumetric method after fusion with sodium carbonate (Piper, 1947). Available phosphorus was determined by extracting with 1 per cent potassium carbonate (Das, 1930). The method for phytin phosphorus was that of Norgard Pederson (1953). Soil reaction was found out using Beckman pH meter and glass electrode.

RESULTS AND DISCUSSION

Phosphorus in wheat grains

In table 1 are presented the data on the content of total, phytin, inorganic, and acid-soluble forms of phosphorus in the wheat grains.

Total phosphorus : The total phosphorus content of the grains varies from 0.241 to 0.434 per cent, the lowest being in the grains from the plot receiving green manure and highest in those from the plot treated with all the inorganic fertilizers (NPK). The application of superphosphate, either alone or in combination with other inorganic fertilizers, has shown an appreciable increase in the content of total phosphorus over the control. These results are in conformity with the reports of earlier workers (Mather, 1929 ; Verma and Das, 1953 ; Chandrasekhara *et al.* 1953 ; Gupta and Das, 1954). The content of total phosphorus in the grains from the plots receiving organic manures, green manures or inorganic fertilizers excluding superphosphate, remains more or less the same as compared to the control, even in certain cases the values fall short of the control, *e.g.*, in the case of plots treated with grean manure and with a purely cereal rotation and green manure in rotation. The organic manures have apparently no effect on the uptake of total phosphorus in grains.

Phytin phosphorus :—Content of phytin phosphorus in wheat grains varies from 0.104 to 0.232 per cent, the lowest being observed in the grains from the plot receiving green manure with a purely cereal rotation and highest in those from the plot receiving complete mineral fertilizers. The content of phytin phosphorus in wheat is almost proportional to the total phosphorus content and the effect of superphosphate, whether alone or in combination with other inorganic fertilizers and green manures, is quite marked as to the increase in the content of phytin as compared to the control. This definite increase in phytin content of wheat grain when treated with phosphatic fertilizers confirms some of the few earlier findings (Bains, 1949 ; Verma and Das, 1953 ; Fujiiwara and Mitsuhashi, 1948) whereas it is contrary to the observation of Young and Greaves (1938) who did not find any such effect.

Some interesting observations can be made from a study of the increase in phytin with respect to total phosphorus in grains obtained from different plots. Table 1, in which ratios of phytin to total phosphorus in grains have been compiled, shows that every treatment has increased the phytin content when compared to the average figure (41.6) for the controls, the exception being observed in the case of plots treated with potassium sulphate and with no green manure and no legume where the ratio of phytin to total phosphorus are 41.0. Here again, the effect is more pronounced in the case of plots receiving superphosphate either alone or in combination with other inorganic fertilizers or green manures, the highest ratio being recorded in the case of superphosphate plus annonium sulphate. Among the bulky organic manures, rape cake falls in line with phosphatic fertilizers and shows corresponding increase in phytin content when applied either alone or with farm yard manure.

Inorganic phosphorus :—The inorganic phosphorus content of the grains shows variation from 0.30 to 0.085 per cent. As in the case of total phosphorus, the phosphatic fertilization has shown an increase in almost all the cases except when in combination with green manure where the content is almost the same as in the grains from the check plots. Among the bulky organic manures, farm yard manure shows an appreciable increase, the heavier dosage showing more pronounced effect. The effect is still more evident in the case of combination with rape cake which alone does not show any effect whereas in combination it has increased this constituent. The other inorganic fertilizers and green manures do not show any increase.

TABLE 1

Contents of different forms of phosphorus in wheat grains

(Expressed as per cent on oven-dry basis)

Plot No.	Treatments (Symbol)*	Phosphorus in grain				Ratio of different forms of phosphorus to total phosphorus		
		Total	Phytin	Inorganic	Acid-soluble	Phytin	Inorganic	Acid-soluble
1	Check 1	0.291	0.126	0.041	0.192	43.4	14.1	66.0
2	F. Y. M. (A)	0.269	0.119	0.053	0.047	44.3	19.6	81.6
3	F. Y. M. (2A)	0.294	0.126	0.064	0.203	43.0	22.0	91.3
4	F. Y. M. (A) + R. C. (A)	0.277	0.150	0.054	0.231	54.1	19.4	83.3
5	R. C. (2A)	0.278	0.154	0.039	0.208	55.5	13.9	74.8
6	N	0.268	0.134	0.043	0.207	49.7	15.9	78.0
7	K	0.288	0.118	0.051	0.238	41.0	17.6	82.8
8	P	0.410	0.211	0.085	0.307	50.3	20.7	74.7
9	K+P	0.391	0.222	0.068	0.297	56.8	17.4	75.9
10	N+P+K	0.434	0.214	0.073	0.316	49.2	17.0	73.0
11	N+P	0.323	0.214	0.064	0.293	66.2	20.0	90.7
12	G.M+Cer.	0.241	0.104	0.039	0.190	43.0	16.2	78.8
13	Check 2	0.309	0.128	0.031	0.199	41.4	10.3	64.2
14	N+K	0.257	0.121	0.030	0.189	42.2	11.5	73.6
15	G.M.	0.270	0.132	0.034	0.215	48.7	12.6	79.7
16	G.M.+P	0.364	0.167	0.042	0.249	46.0	11.7	68.4
17	No G.M. and No Leg.	0.322	0.132	0.048	0.216	40.8	15.0	67.0
18	Check 3	0.306	0.122	0.040	0.196	40.0	12.9	65.7

**Treatments*: Check 1, Check 2, Check 3—controls; F. Y. M. (A) and F. Y. M. (2A)—4000 lb. and 8000 lb. of farm yard manure per acre; R. C. (A) and R. C. (2A)—rape cake at 20 lb. and 40 lb. of nitrogen per acre; N—ammonium sulphata at 40 lb. of nitrogen per acre; K—potassium sulphate at 50 lb. of K_2O per acre; P—superphosphate at 80 lb. of P_2O_5 per acre; G. M.—green manure; Cer.—cereal rotation; No. G. M. and No. Leg.—no green manure and no legume rotation; +indicates combination.

There is a corresponding increase in inorganic phosphorus in relation to total phosphorus in grains in almost all the cases except in two cases. One such is the plot receiving combined ammonium sulphate and potassium sulphate and the other is that receiving green manure with super. The relative increase in the content of inorganic phosphorus as compared to the control in some cases is about 40 to 50 per cent. This is found in the plots receiving farm yard manure alone or in combination with rape cake and all the inorganic fertilizers, the only exception being the plot having sulphate of ammonium and potassium.

Acid-soluble phosphorus :—The acid-soluble phosphorus includes phytin, inorganic, and ester type of phosphorus. The content of acid-soluble phosphorus in grains follows the general pattern of small increase in most of the cases over the control; phosphatic fertilizers, of course, resulted in more pronounced increase as compared to others. Among the organic manures, farm yard manure shows more increase, and even the dose may be a factor for this. Almost all the treatments show a considerable increase in the content of acid-soluble phosphorus as compared to the total content of this element. The relative increase is more marked in the case of farm yard manure(2A) as well as in the case of ammonium sulphate and superphosphate in combination.

Correlation of total phosphorus with other forms of phosphorus in wheat

Statistical analysis was carried out to study the correlation, if any, between total and other forms of phosphorus in wheat grains under study and the results are presented in table 2.

TABLE 2

Correlation coefficients

Constituents (Forms of phosphorus)	Correlation coefficients	Significance
Total and phytin	+0.6281	at 1% level
Total and acid-soluble	+0.8170	„ 1% level
Total and inorganic	+0.7032	„ 1% level

It is evident that acid-soluble, phytin, and inorganic forms of phosphorus are significantly (at 1 per cent level) and positively correlated with the total content of phosphorus in the wheat grains.

Relationship of phytin to other forms of phosphorus components in grains have been studied by comparing the relation of phytin phosphorus to other forms of phosphorus in wheat. The increase of phytin to total phophorus has been discussed earlier. The relation of phytin to acid-soluble forms of phosphorus follows the similar pattern. This is expected as the acid-soluble phosphorus is linearly and positively correlated with total phosphorus. This is true in all the cases of phosphatic treatments except when in combination with green manure.

Influence of farm yard manure shows a lower ratio of phytin to inorganic phosphorus as compared to the average ratio of 3.3 in check plots. This suggests that farm yard manure appears to have inhibitory effect on the synthesis of phytin from inorganic phosphorus. Green manure and rape cake, on the other hand, show a definite influence on the

possibility of a larger synthesis of phytin from inorganic phosphorus. The effect of phosphatic fertilizers has been such as to increase both phytin and inorganic phosphorus contents in grains under their influence, and the increases are similar so as to balance a possible synthesis of phytin in a manner which seems to be in accordance with the grains derived from check plots. Only in the case of superphosphate alone, there appears to be some inhibition in its synthesis from inorganic phosphorus, the latter being relatively more in amount than the former.

Potassium sulphate alone shows that phytin content in relation to inorganic phosphorus is less than the control. The effect of ammonium sulphate, either alone or in combination with super or potassium sulphate, demonstrates a higher ratio of phytin to inorganic phosphorus and suggests a larger synthesis of phytin under the influence of this fertilizer. The increase in ratio is appecriably high when it is combined with potassium sulphate. The plot having all the three inorganic fertilizers, however, maintains the ratio at the same level as in the control.

Phytin phosphorus is positively and significantly correlated (at 1 per cent level) with the inorganic phosphorus in the grains ($r= +0.7212$) whereas it is negatively correlated with protein in grains and the latter correlation is not significant.

Phosphorus in soils

Table 3 shows the content of total, available, and phytin phosphorus in soils. pH values of the soils do not show any variation. Manures and fertilizers manifest their influence in significantly increasing the phosphorus content of the soils. Plots treated with super alone or in combination with other inorganic fertilizers and green manure have

TABLE 3

Content of total, phytin, and available phosphorus in soils
(Expressed as per cent on oven-dry basis)

Plot No.	Treatments (Symbol)*	pH of soil	Phosphorus in soil			Available P/ Total P
			Total	Available	Phytin	
1	Check 1	7.8	0.048	0.0013	0.0021	2.7
2	F.Y.M. (A)	7.8	0.055	0.0010	0.0021	1.8
3	F.Y.M. (2A)	7.8	0.085	0.0015	0.0027	1.8
4	F.Y.M. (A)+R.C. (A)	7.7	0.095	0.0016	0.0030	1.8
5	R.C. (2A)	7.8	0.057	0.0014	0.0033	2.5
6	N	7.8	0.053	0.0016	0.0030	3.0
7	K	7.8	0.059	0.0012	0.0032	2.0
8	P	7.7	0.108	0.0031	0.0035	2.7
9	K+P	7.6	0.098	0.0029	0.0038	2.9
10	N+P+K	7.7	0.098	0.0031	0.0040	3.1
11	N+P	7.8	0.093	0.0032	0.0033	3.4
12	G.M+Cer.	7.9	0.053	0.0017	0.0025	3.2
13	Check 2	7.9	0.046	0.0016	0.0022	3.6
14	N+K	7.9	0·034	0.0015	0.0021	4.4
15	G.M.	7.7	0.055	0.0016	0.0030	3.0
16	G.M.+P	7.9	0.071	0.0017	0.0033	2.4
17	No. G.M. & No. Leg.	7.9	0.046	0.0010	0.0028	2.2
18	Check 3	7.8	0.043	0.0009	0.0026	2.1

*Details given in table 1

shown about double the phosphorus content as compared to the phosphorus content of the control. Bulky organic manures have also considerably increased the phosphorus content of the soils while green manuring in rotation or with a purely cereal rotation has not shown any significant change in the phosphorus content of the soils. Ammonium sulphate or potassium sulphate alone has increased the phosphorus content only to a very small extent as compared to the control. When these two fertilizers have been applied together, the phosphorus content of the plot, on the other hand, shows much reduction.

Available phosphorus content runs approximately parallel to the total phosphorus content of the plots. The available phosphorus is found to be higher in the plot when superphosphate has been applied and a slight increase is also exhibited in the case of plots treated with ammonium sulphate alone or with super. The effect of ammonium sulphate in increasing availability of phosphorus has been reported by Pierre and Norman (1953). The level of available phosphorus in relation to total phosphorus is found to be higher in case of green manures whenever they have been applied, a case which supports the assertion of various workers that green manures help in increasing the availability of phosphorus in soils (Pierre and Norman, 1953).

It is known that a portion of soil organic phosphorus exists as phytin and is related to soil type, pH, *etc.* (Bower, 1949). In the present investigation, an attempt has been made to show the variation in the content of phytin under the influence of fertilizers and also to find out whether it has any relation to the phytin content of the grains. The figures obtained in the present investigation are lower than the available figures reported in literature. The phytin phosphorus varies from 0.002 to 0.004 per cent and is somewhat proportional to total phosphorus. The lower values of phytin may be due to the deficient organic matter and calcareous nature of the soils. In alkaline and calcareous soils, the existence of phytin is of lesser possibility.

Correlation of phosphorus in soil with that in grain

The correlations, worked out statistically, between total as well as available phosphorus in soil with the different forms of phosphorus in grains are given in table 4.

TABLE 4

Correlation of phosphorus in soil with phosphorus in grain

Constituents	Correlation coefficient	Significance
Total phosphorus in soil/Total phosphorus in grain	+0.6653	@ 1% level
„ /Phytin phosphorus in grains	+0.9756	„
„ /Inorganic phosphorus in grain	+0.8525	„
„ /Acid-soluble phosphorus in grain	+0.8727	„
Available phosphorus in soil /Total phosphorus in grain	+0.7048	„
„ /Phytin phosphorus in grains	+0.8432	„
„ /Inorganic phosphorus in grain	+0.7179	„
„ /Acid-soluble phosphorus in grain	+0.8300	„
Phytin phosphorus in soil/Phytin phosphorus in grain	+0.7434	„

The table shows that the correlations are highly significant and positive. Apparently phytin phosphorus in grains is highly correlated with the total phosphorus content of the soil, next come acid-soluble and inorganic phosphorus in succession. Similar order of

correlation is exhibited by different phosphorus components of grains with available phosphorus of soil and the phytin content again exhibits highest correlation, followed by acid-soluble, inorganic and total phosphorus respectively. It is interesting to find that there exists a positive and significant correlation between phytin phosphorus in soil and that in grain.

SUMMARY

In order to study the influence of fertilizers and manures on the content of total, phytin, inorganic, and acid-soluble phosphorus in wheat, eighteen samples of wheat grains raised from plots under different treatments were analysed for these constituents. Relation to soil phosphorus was also studied.

Phosphatic fertilizers have resulted in a significant increase in total phosphorus in wheat whereas other inorganic fertilizers, organic manures and green manuring do not appear to have any influence. Application of superphosphate, either alone or in combination with other inorganic fertilizers or green manure, shows a significant increase in all the forms of phosphorus whereas ammonium sulphate and potassium sulphate, either singly or in combination have the reverse effect. Farm yard manure also does not show any increase in total and phytin phosphorous, although rape cake which does not increase total phosphorus has markedly increased the phytin phosphorus. Combined effect of rape cake and farm yard manure has resulted in a significant increase in phytin and inorganic phosphorus content. Green manure alone shows a decrease in total, phytin, and inorganic phosphorus while acid-soluble phosphorus is practically without any effect.

Total phosphorus in grains bears a significant and positive correlation with phytin, inorganic, and acid-soluble phosphorus. Phytin phosphorus shows a significant and positive correlation with inorganic phosphorus.

The application of superphosphate to the soil has increased the total phosphorus content almost double that of control and bulky organic manures have also brought about considerable increase. Green manuring has not shown any significant change while other inorganic fertilizers have increased the total phosphorus content to a very limited extent. The level of available phosphorus is higher in case of green manuring and also in case of application of ammonium sulphate. Phosphatic fertilisation has resulted in higher values of available phosphorus over that of control, but the relative level in relation to total phosphorus remains the same. The effect of organic manures have brought lower values of available phosphorus in relation to total phosphorus of the soils. The content of phytin phosphorus is, to a certain extent, proportional to the total amount present in soil.

Statistical correlation has been studied in case of total phosphorus and available phosphorus in soils with the corresponding values of total, phytin, inorganic, and acid-soluble phosphorus of grains. The correlations are positive and significant at 1% level in all the cases.

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Effect of Farmyard Manure and Superphosphate on Berseem Yield, Nodulation and on Nitrogen and Available Phosphorus Contents of the Soil

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The results of experiments reported earlier (Parr and Bose, 1944; 1947) relate to the first cycle of the rotation in which berseem was manured consecutively for three years and followed by unmanured wheat for three succeeding years. The increase in the yield of berseem green fodder over the control varied from 100 to 300 per cent; superphosphate had generally given higher yields of fodder than farmyard manure, but the differences were generally not significant. With wheat, significant increases in yields over the control were obtained wherever the dose of P_2O_5 applied to berseem was 64 lb., either as superphosphate singly or superphosphate in combination with farmyard manure.

The second cycle of the rotation was started in 1948-49, partly to confirm the results obtained in the first cycle, and partly to study the effect of phosphate manuring on seed production and nodulation of berseem and on the nitrogen and available phosphorus contents of the soil.

MATERIAL AND METHOD

The experiment was conducted for three years, 1948-49 to 1950-51. Berseem was manured every year and grown in rotation with unmanured cowpeas. The manure and the fertilizer were applied uniformly by broadcasting and incorporated into the soil by ploughing. Three cuttings of berseem green fodder were taken and then the crop was left to seed.

The following treatments were applied to berseem before sowing :—

A.	Farmyard manure		16 lb.	P_2O_5 per acre
B.	Farmyard manure		32 lb.	,,
C.	Farmyard manure		64 lb.	,,
D.	Superphosphate		16 lb.	,,
E.	Superphosphate		32 lb.	,,
F.	Superphosphate		64 lb.	,,
G.	Superphosphate + Farmyard manure	8 lb. + 8 lb.	16 lb.	,,
H.	Superphosphate + Farmyard manure	8 lb. + 24 lb.	32 lb.	,,
I.	Superphosphate + Farmyard manure	8 lb. + 56 lb.	64 lb.	,,

J.	Farmyard manure + Superphosphate	8 lb. 24 lb.	32 lb.	,,
K.	Farmyard manure + Superphosphate	8 lb. 56 lb.	64 lb.	,,
L.	No manure			

Farmyard manure contained 0.52 per cent nitrogen, 0.312 per cent P_2O_5 and 0.429 per cent K_2O and triple superphosphate contained 38.68 per cent P_2O_5. Farmyard manure supplying 8 lb. P_2O_5 contains 13.3 lb. N and 11 lb. K_2O.

The experiment was laid out in randomised blocks with six replications and a plot size of 1/40 acre (approximately).

The soil of the experimental field is sandy loam and has the following physical and chemical composition : pH—7.5; Clay—12.4 per cent; Silt—8.0 per cent; Fine sand—74.3 per cent; Coarse sand—0.98 per cent; Nitrogen—0.05 per cent; P_2O_5 (total)—0.07 per cent; P_2O_5 (available)—0.017 per cent; CaO—0.65 per cent.

In 1951, after growing the third crop of berseem, composite soil samples were collected to study the nitrogen and the available phosphorus contents of the plots under different treatments. Observations on root nodules were taken in 1950-51 on ten plants dug out from each plot of three blocks taken at random. Nodules were classified as small, medium and large sizes, one large nodule being equal to four small ones and one medium nodule equivalent to two small ones.

RESULTS AND DISCUSSION

Yield of green fodder

The yields of berseem green fodder due to different treatments for the three years are presented in table 1 (*vide* p. 43).

The treatments are arranged below in descending order of merit. Treatments falling under the same bar do not differ significantly amongst themselves.

1948-49	I,	K,	C,	F,	B,	J,	H,	E,	G,	D,	A,	L.
1949-50	F,	I,	K,	E,	J,	C,	H,	D,	B,	G,	A,	L.
1950-51	K,	F,	I,	J,	E,	C,	H,	D,	B,	G,	A,	L.
1948-49 to 1950-51	I,	K,	F,	J,	C,	E,	H,	B,	D,	G,	A,	L.

A serial analysis of three years' yield data relating to green fodder indicates that the effects due to treatments and years are highly significant (at 1 per cent level). The interaction between treatments and years is not significant.

TABLE 1

Yield of berseem green fodder in maunds per acre

Treatment	P_2O_5 (lb. per acre)	Yield of green fodder			
		1948-49	1949-50	1950-51	1948-49 to 1950-51
A. Farmyard manure ...	16	196.50	153.28	75.52	141.76
B. Farmyard manure ...	32	298.34	267.35	169.52	245.07
C. Farmyard manure ...	64	348.56	349.68	247.75	315.33
D. Superphosphate ...	16	210.97	276.96	172.79	220.24
E. Superphosphate ...	32	271.64	392.25	271.64	311.84
F. Superphosphate ...	64	348.19	489.61	363.40	400.40
G. Superphosphate + Farmyard manure ...	8 8	224.22	227.30	159.72	203.75
H. Superphosphate + Farmyard manure ...	8 24	272.58	301.05	217.97	263.87
I. Superphosphate + Farmyard manure ...	8 56	405.69	450.97	356.12	404.26
J. Superphosphate + Famyard manure ...	24 8	276.86	389.36	300.89	322.37
K. Farmyard manure + Superphosphate ...	8 56	366.30	449.29	387.86	401.15
L. No manure ...		127.70	94.84	21.38	81.31
'F' test ...		**	**	**	**
S. E. of mean ...		±21.48	±26.21	±21.41	±19.16
C.D. at 5 per cent level ...		60.75	74.62	60.81	54.31
C.D. at 1 per cent level ...		80.80	99.25	81.10	72.33
Mean yields for years ...		279.01	320.22	228.71	
'F' test ...		significant at 1 per cent level			
S.E. of mean ±4.80 ...		C.D. at 5 per cent = 13.44 C.D. at 1 per cent = 17.17			

** indicates significant at 1 per cent level.

(*a*) *Fertilizer treatments* : There is no significant difference between the yields due to 64 lb. P_2O_5 per acre applied in the form of superphosphate singly and superphosphate in combination with farmyard manure, though these treatments are significant over farmyard manure supplying the same amount of P_2O_5 per acre. The treatments supplying 32 lb. P_2O_5 per acre in the form of superphosphate alone or superphoshate combined with farmyard manure yielded as good as farmyard manure supplying double the amount of P_2O_5 *i.e.*, 64 lb. per acre. Similarly, the lowest dose of 16 lb. P_2O_5 per acre applied either as superphosphate alone or superphosphate combined with farmyard manure produced significantly higher yields than farmyard manure supplying the same amount of P_2O_5. All the fertilizer treatments and the manurial treatments are significant over the 'no manure' control.

(*b*) *Years :* The mean yields of berseem green fodder for the three years, as will be seen from table 1, differ significantly from one another. The year 1949-50 showed highest yields partly due to delay in the third cutting and was significant over the other two seasons. The year 1948-49 was an average year and the mean yield obtained was significant over that in 1950-51. Since the interaction between treatments and years is not significant, it indicates that the treatments have maintained their respective positions, irrespective of the effects due to season.

Yield of seed

TABLE 2

Yield of berseem seed in maunds per acre

Treatment	P_2O_5 (lb. per acre)	Yield of berseem seeds			
		1948-49	1949-50	1950-51	1948-49 to 1950-51
A. Farmyard manure ...	16	2.34	0.56	1.79	1.56
B. Farmyard manure ...	32	3.78	1.45	2.48	2.57
C. Farmyard manure ...	64	4.16	1.62	3.41	3.06
D. Superphosphate ...	16	2.40	1.33	2.40	2.04
E. Superphosphate ...	32	3.90	1.51	3.17	2.86
F. Superphosphate ...	64	3.69	1.97	3.67	3.11
G. Superphosphate ... + Farmyard manure ...	8 8	3.71	0.56	2.49	2.25
H. Superphosphate ... + Farmyard manure ...	8 24	2.92	1.98	3.15	2.68
I. Superphosphate ... + Farmyard manure ...	8 56	4.34	2.10	3.93	3.46
J. Farmyard manure ... + Superphosphate ...	8 24	4.04	1.39	3.43	2.95
K. Farmyard manure ... + Superphosphate ...	8 56	4.30	1.98	3.74	3.34
L. No manure ...		1.38	0.11	0.39	0.63
'F' test ...		**	**	**	**
S.E. of mean ...		±0.34	±0.16	±0.26	±0.17
C.D. at 5 per cent level ...		0.96	0.44	0.74	0.48
C.D. at 1 per cent level ...		1.27	0.59	0.99	0.64
Mean yield for years ...		3.41	1.38	2.84	
'F' test ...		significant at 1 per cent level			
S.E. of mean ± 0.068 ...		C.D. at 5 per cent level=0.22 C.D. at 1 per cent level=0.30			

** indicates significant at 1 per cent level.

The treatments are arranged below in descending order of merit as indicated by the statistical analysis of data for the individual years and the combined analysis of three years' data. The treatments falling under the same bar do not differ significantly amongst themselves.

1948-49 I, K, C, J, E, B, G, F, H, D, A, L.

1949-50 I, K, H, F, C, E, B, J, D, G, A, L.

1950-51 I, K, F, J, C, E, H, G, B, D, A, L.

1948-49 to 1950-51 I, K, F, C, J, E, H, B, G, D, A, L.

A serial analysis of the three years' data shows that the effects due to treatments and years are highly significant (at 1 per cent level) and that the interaction between treatments and years is significant at 5 per cent level.

(*a*) *Fertilizer treatments*: There is no significant difference in yields of seed due to 64 lb. P_2O_5 per acre applied in the form of superphosphate alone, farmyard manure alone or farmyard manure mixed with superphosphate. The response is similar in regard to the dose of 32 lb. P_2O_5 per acre. As regards the lowest dose, farmyard manure at 8 lb. P_2O_5 +superphosphate at 8 lb. P_2O_5 per acre gave the highest yield and was significant over farmyard manure at 16 lb. P_2O_5 per acre. All the fertilizer and manurial treatments produced significantly higher yields of seed than the 'no manure' control. There was a corresponding increase in the yield for an increase in the dose of phosphate applied per acre, though the differences were not significant in all the cases. For the same amount of P_2O_5, superphosphate, in general, has given higher yields when combined with farmyard manure than superphosphate or farmyard manure alone, though the differences were not significant.

(*b*) *Years*: It will be seen from table 2 that the yield of berseem seed during 1948-49 was highest followed by that obtained during 1950-51 and was lowest during 1949-50. The mean yield for the year 1948-49 was significant over that for 1950-51 which in turn was significant over that for 1949-50. The season × treatment interaction is significant which may be attributed to the seasonal factor; the year 1949-50 being poor, 1948-49 good and 1950-51, a medium one.

Root nodule studies

The average number of nodules per plant under the various treatments at different stages of growth standardised on the basis of small nodules, are given in table 3.

TABLE 3

Average number of nodules per plant at various stages of growth

	24th Nov.	15th Dec.	5th Jan.	24th Jan.	14th Feb.	4th Mar.	30th Mar.	21st Apr.	23rd May
A.	9.66	12.83	16.96	19.66	23.43	24.43	22.40	20.90	10.73
B.	8.93	17.46	21.63	26.70	33.88	41.06	40.26	31.36	16.33
C.	11.13	22.13	29.80	42.70	50.33	65.26	66.73	65.43	35.51
D.	9.86	20.43	24.80	37.70	56 26	44.40	41.33	38.46	19.63
E.	9.53	28.36	37.70	60.43	72.26	73.86	71.20	68.93	35.26
F.	9.46	28.36	51.00	91.53	102.92	93.83	92.93	86.13	45.30
G.	9.20	17.60	24.83	45.60	52.26	47.10	45.50	42.86	23.16
H.	8.53	22.70	34.86	47.93	65.33	58.93	57.86	57.53	28.50
I.	9.06	26.66	50.23	77.96	100.00	93.86	95.86	93.20	47.73
J.	11.06	27.16	38.16	47.21	60.20	60.83	57.83	57.06	28.50
K.	10.73	27.53	47.90	83.83	107.13	97.20	98.06	95.00	49.66
L.	8.40	9.06	10.16	11.50	14.50	17.43	15.73	14.46	7.13
'F' test	not sig.	**	**	**	**	**	**	**	**
C.D. at 5% level		4.90	7.95	33.66	29.65	24.54	27.65	21.66	11.42
C.D. at 1% level		6.69	10.84	45.90	40.43	33.47	37.72	29.54	15.58

** indicates significant at 1 per cent level.

Except at first nodule count taken after three weeks of sowing, differences among the treatments were found to be highly (at 1 per cent level) significant. Treatmants K, F and I (64 lb. P_2O_5 per acre) were distinctly superior to the 32 lb. doses in all the observations. Similarly, 32 lb. doses E, J and H were significantly better than the 16 lb. doses. The 'no manure' treatment produced the least number of nodules at every stage. Treatment C (farmyard manure at 64 lb. P_2O_5) showed a very slow development of nodules. It was superior to B, A and L up to the fifth observation, but later on it showed an increase in the number of nodules. A decline in the number of nodules after the sixth and seventh observations was found under all the treatments.

Nitrogen and available phosphorus contents of the soil

Table 4 presents the data on nitrogen and available phosphorus of the soil under P_2O_5 levels applied as superphosphate, farmyard manure and combination of the two. Surface soil (0-6 inches) and sub-soil (6-12 inches) were only taken up for analysis.

TABLE 4

Nitrogen and available P_2O_5 contents of the soils

(Expressed as per cent on oven-dry basis)

Source	Doses of P_2O_5 per acre (in lb.)			
	0	16	32	64
Surface soil (0-6 inches) (Nitrogen content)				
1. Farmyard manure		0.077	0.074	0.091
2. Superphosphate		0.082	0.086	0.091
3. Superphosphate at 8 lb.+Farmyard manure		0.090	0.089	0.091
4. Farmyard manure at 8 lb.+Superphosphate		...	0.093	0.087
Average	0.070	0.083	0.086	0.090

TABLE 4—(*Contd.*)

Source	Doses of P_2O_5 per acre (in lb.)			
	0	16	32	64
Sub-soil (6-12 inches)				
1. Farmyard manure		0.053	0.053	0.076
2. Superphosphate		0.073	0.071	0.056
3. Superphosphate at 8 lb.+Farmyard manure		0.064	0.065	0.056
4. Farmyard manure at 8 lb.+Superphosphate		...	0.066	0.052
Average	0.050	0.063	0.064	0.060
Surface soil (0-6 inches) (Available P_2O_5 content)				
1. Farmyard manure		0.0160	0.0181	0.0164
2. Superphosphate		0.0180	0.0170	0.0186
3. Superphosphate at 8 lb.+Farmyard manure		0.0174	0.0200	0.0256
4. Farmyard manure at 8 lb.+Superphosphate		...	0.0228	0.0228
Average	0.0103	0.0171	0.0195	0.0209
Sub-soil (6-12 inches)				
1. Farmyard manure		0.0152	0.0176	0.0136
2. Superphosphate		0.0153	0.0164	0.0170
3. Superphosphate at 8 lb.+Farmyard manure		0.0133	0.0228	0.0248
4. Farmyard manure at 8 lb.+Superphosphate		...	0.0216	0.0180
Average	0.0103	0.0146	0.0196	0.0184

Nitrogen : It is seen that the nitrogen content of the soil under different fertilizer treatments is considerably higher in the surface soil (0—6 inches). A marked increase in the soil nitrogen content over the control has been brought about by phosphate manuring of berseem, grown and manured consecutively for three years in rotation with unmanured cowpeas. In general, an increase in nitrogen content of the soil has been observed for a corresponding increase in the phosphate applications in the surface soil and this effect was not well marked in the sub-soil (6—12 inches).

Available P_2O_5 : The results of analysis of soil samples for available phosphorus are almost similar to those observed in regard to the nitrogen content of the soil. The phosphate treatments applied to the berseem crop have rendered the soil phosphates more available and the increase in avilability has been well marked over the 'no manure' control. Increasing doses of phosphate had increasing effect on phosphate availability. When superphosphate was applied in conjunction with farmyard manure, the percentage of available phosphate was higher than where these were applied singly.

Phosphate manuring of berseem has resulted in significant increases in yields of green fodder and seed over those from the 'no manure' control. The results from the no manure plots showed an abrupt fall in the yield of fodder from 127.70 maunds per acre in 1948-49 to 21.38 maunds per acre in 1950-51. This is attributed to the inability of the soil under the experiment to meet the normal requirement of the berseem crop due to the absence of phosphate in the available form. This is further confirmed by the results from the phosphate treated plots where the yields of berseem have been maintained at a fairly high level. The results clearly indicate the necessity of phosphate manuring of berseem for higher yields. The results are in close conformity with those obtained by Parr and Bose (1944) in the first cycle and also as reported by Blaser, Volk and Smith (1941), Mursell (1944), Sen and Bains (1951, 1952) with regard to the fodder yields and others *viz.*, Evans (1933), Hosking (1937), Tydsal (1937) and Gusev (1939) with regard to both fodder and seed yields.

The data on the number of nodules show clearly that the phosphate treatments favoured nodulation on berseem roots and the number of nodules increased with increasing doses of phosphate. Treatment F (superphosphate at 64 lb. P_2O_5) and K (farmyard manure at 8 lb. P_2O_5+superphosphate at 56 lb. P_2O_5) indicated early nodulation, whereas treatment I (superphosphate at 8 lb. P_2O_5+farmyard manure at 56 lb. P_2O_5) and C (farmyard manure at 64 lb. P_2O_5) seemed to be slow in this respect. Thus superphosphate alone appears to stimulate the earliest nodulation in berseem. These results are in close conformity with those obtained by Ludecke (1941) and Smith (1944).

An increase of the nitrogen content in the soil has been brought about by the phosphate fertilization of berseem. This may be partly due to the increased microbiological activity of the nitrogen fixing bacteria as found in the increase of nodulation under the phosphate treated plots and partly due to the increased amount of crop residues which resulted from phosphate applications. The results obtained are in harmony with those obtained by other workers in the field (Giobel, 1926 and Virtanen, 1945).

Phosphate fertilization of berseem has further increased the available phosphate content of the soil. The percentage increase is well marked under treatments where superphosphate was applied in combination with farmyard manure. The conversion of soil phosphate into available form may be due to (1) production of large quantities of carbon dioxide during decomposition of organic matter leading to lowering in pH of the soil solution (Moser, 1942 and Oberholzer, 1936) and (2) conversion under the influence of decomposing organic matter to organic phosphates which are better available (Shrikhande, 1948 and Das, 1945).

SUMMARY

A field trial was conducted during 1948-49 to 1950-51 to study the effect of phosphate applications at 16 lb., 32 lb. and 64 lb. P_2O_5 per acre as farmyard manure alone, superphosphate alone and in certain combinations of the two, on the yields of green fodder, seed, and nodulation of berseem and also on the nitrogen and available phosphate contents of the soil.

Phosphate application to berseem resulted in significant increases in yields of both green fodder and seed. For an increase in the rate of application of phosphate per acre, there was a corresponding increase in the yields. Phosphate at 64 lb. P_2O_5 per acre produced significantly higher yields of green fodder over those due to 32 lb. P_2O_5 which, in turn, was significant over 16 lb. P_2O_5 per acre. For the same amount of phosphate, superphosphate alone or in combination with farmyard manure, generally, yielded higher than farmyard manure alone, though the differences were not significant in all the cases.

A fall in the yield of berseem fodder from 127.70 maunds per acre in 1948-49 to 21.38 maunds per acre in 1950-51 and the maintenance of yields at a fairly high level under phosphate treated plots clearly indicates the necessity of phosphate fertilization of berseem for higher yields.

Phosphate treatments favoured nodulation on berseem roots and the number of nodules increased with the increasing doses of phosphate.

Phosphate fertilization of berseem for three years increased the nitrogen content of the soil. The nitrogen content increased with increased applications of phosphate, particularly in the surface soil (0—6 inches).

The available phosphate content of the soil under different phosphate treatments indicated that phosphate fertilization of berseem rendered the soil phosphate more avail-

able. This effect was more pronounced in treatments where superphosphate and farmyard manure were applied in combination.

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Effect of Tractor Ploughing in Black Soils of Malwa

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The changes in the physical condition of the soil due to tillage operations are of great importance from the point of view of practical agriculture and in the maintenance of tilth, because these changes are inherently associated with the fertility status of a soil. The success of soil conservation measures and the maintenance of soil productivity depend on thorough understanding of the effect of tillage implements on soil properties.

The Russian workers (Joffe, 1945) found that deep ploughing of chernozem soils by heavy machinary results in adverse effects on their physical and chemical properties. The Central Tractor Organisation, under the Government of India, are employing various types of tractors for cultivation of a large tract of culturable waste land, *e.g.* heavy tractors are being utilised on black cotton soils of Malwa. It is known that these black soils of India are, to a great extent, analogous to chernozem of Russia and a great many properties of black soils of India and chernozem are quite common. Studies on the change in physical and chemical properties of soils under the influence of tillage operations, particularly by deep ploughing, under Indian climatic conditions have not been reported earlier and the direct definition of the changes in structure of the soil under the influence of tillage are very scarce and not systematic. It was, therefore, thought to be of considerable importance to study the changes brought about in some important soil properties by tractor ploughing.

The present investigation is a preliminary work to study the changes in physical, chemical, and biological properties in Black Cotton Soils which form one of the most important group of soils in India.

MATERIAL AND METHODS

Representative soil samples were collected from the virgin area, tractor ploughed area and also from the ploughed up and cultivated area (*i.e.*, tractor ploughed and crops taken) from four villages, such as Maliwara, Salkanpur, Bari, Obaidullaganj of Bhopal State. Only surface soil samples (0 to 12 in.) and sub-surface soil samples (12 to 24 in.) were collected with the help of posthole auger. The tractor ploughing was done only to a depth of 12 inches.

International method A was followed for mechanical analysis. Moisture holding capacity, apparent and real specific gravity, pore space and volume expansion were determined with the help of Keen-Raezowski box by the modified procedure of Coutts (1930). Regarding Atterberg's constants, the upper and lower plastic limits were determined by the methods described by Russell and Whear (1928) and sticky point by the method of Keen and Couts (1928). The aggregate analysis was carried out by the method developed by Russell and Tamhane (1940).

Total bacterial counts were done by Thornton Agar Media, for determining nitrogen fixing power Ashby's mannite solution was used and nitrifying power of the soils were determined in liquid media using Omenliasky and Winograski solution No. I and II.

TABLE 1

Mechanical composition of soils

S. No.	Place	Type	Depth (Inches)	Coarse Sand %	Fine Sand %	Silt %	Clay %	Silt & Clay %	Mois-ture %	Loss on solution %	Total	Carbo-nates' %	Field Mois-ture.
1	Bari	Virgin	0—12	0.70	28.76	17.36	45.80	63.16	6.93	2.71	99.97	Nil	—
2	,,	,,	12—24	0.63	26.33	23.24	40.60	63.84	6.24	3.24	99.98	Nil	—
3	,,	Tr. Crop*	0—12	0.68	20.09	19.64	49.84	69.48	7.03	2.13	99.41	0.548	—
4	,,	,,	12—24	0.68	19.90	19.80	51.56	71.36	7.71	2.40	99.05	0.329	—
5	,,	Tr. Plug†	0—12	1.88	19.67	20.16	49.44	69.60	6.57	1.92	99.64	0.548	—
6	,,	,,	12—24	1.88	19.33	20.04	50.60	70.64	5.59	2.52	99.92	0.592	—
7	,,	Virgin	0—12	2.78	31.72	21.20	34.96	56.16	3.76	4.20	98.62	0.548	5.6
8	,,	,,	12—18	3.79	34.58	29.04	27.20	56.24	6.19	1.90	101.70	0.658	—
9	,,	Tr. Plug	0—12	3.76	44.49	20.56	27.84	48.40	4.04	1.50	101.10	Nil	9.8
10	,,	,,	12—18	3.71	35.39	19.84	34.16	54.00	7.23	1.80	101.13	0.9219	—
11	Maliwara	,,	0—12	0.27	15.67	21.68	52.60	74.28	7.52	2.21	99.95	0.373	—
12	,,	,,	12—24	0.27	16.10	19.72	53 84	73.56	7.44	1.61	99.99	0.329	—
13	Salkanpur	Virgin	0—12	11.51	28.41	14.00	38.60	52.60	4.95	2.33	99.80	1.004	—
14	,,	,,	12—24	8.33	24.68	14.40	43.30	57.70	5.47	3.17	99.41	2.085	—
15	Obaidullaganj	,,	0—12	0.86	19.96	23.36	49.52	72.88	7.19	1.60	101.49	0.548	—
16	,,	,,	12—18	1.19	26.32	24.96	41.52	66.48	5.73	1.20	101.32	3.803	—

*Tractor ploughed and crop taken.
†Tractor ploughed.

RESULTS AND DISCUSSION

Mechanical Properties of Soils

Mechanical composition of the soils : The soils belong to the textural group of clay or clay loam as is evident from the data on mechanical composition given in table 1. The virgin and the tractor ploughed soils do not reveal any marked difference so far as their mechanical composition is concerned. Practically, no difference is observed in the moisture content, as determined in the laboratory, of the tractor ploughed and virgin soils though the field moisture is found to be more in tractor ploughed soils than in the virgin soils.

Single value physical constants : The moisture holding capacity of these soils ranges from 39 to 70 per cent and is proportional to clay content except in a few cases. However, the variations in the virgin and tractor ploughed soils are not of great magnitude. The ranges in the values of apparent specific gravity indicate the heavy texture of the soils. The tractor ploughed soils have higher values for apparent specific gravity than the virgin soils. It is interesting to note that there is practically no difference in the sub-soil as the depth of ploughing was 12 inches only. These results are in good agreement with those obtained by Johnston's volumeter (Johnson, 1945). The very high volume expansion, such 16 to 26 per cent of those soils are characteristic of black soils in consideration to the high percentage of clay. But, there is no significant difference in volume expansion of virgin and tractor ploughed soils.

TABLE 2

(Keen-Raczkowaki determinations)

S. No.	Place	Type	Depth (inches)	Moisture Holding Capacity	Real Sp. gr.	App. Sp. gr.	Vol. Expansion %
1.	Bari	Virgin	0—12	57	2.58	1.21	24.7
2.	,,	*Tr. Crop.	,,	58	2.13	1.31	21.4
3.	,,	†Tr. Plug.	,,	59	2.80	1 41	23.8
4.	,,	Virgin	12—24	66	2.20	1.27	26.8
5.	,,	Tr. Crop.	,,	66	2.30	1 27	23.3
6.	,,	Tr. Plug.	,,	60	2.58	1.34	25.4
7.	,,	Virgin	0—12	44.85	2.59	1.33	20.3
8.	,,	Tr. Plug.	,,	39.41	2.22	1.56	19.6
9.	,,	Virgin	12—18	43.57	2.99	1.23	16.2
10.	,,	Tr. Plug.	,,	41.59	2.61	1.23	21.4
11.	Maliwara	,,	0—12	63	2.86	1.39	26.0
12.	,,	,,	12—24	70	2.40	1.28	23.7
13.	Salkanpur	Virgin	0—12	58	2.35	1.35	18.5
14.	,,	,,	12—24	53	2.35	1.33	20.1
15.	Obaid.	,,	0—12	54 48	2.91	1.30	26.7
16.	,,	,,	12—28	52.80	2.92	1.24	20.2

*Tractor ploughed and crop taken.

†Tractor ploughed.

Atterberg's constant : Soil consistency as defined by Atterberg (1928) is the behaviour of soil towards external influence. The Atterberg constants, such as upper plastic limit, lower plastic limit, plastic number values are higher in ploughed soils as compared to the virgin soils, These values are fairly related to clay content.

The sub-surface soils are unaffected and have almost the similar upper and lower plastic limits values for virgin as well as for tractor ploughed soils. Since the virgin soils possess lower values for plastic number, these soils may have lesser tendency of puddling as compared to tractor ploughed soils. Since the values for upper plastic limit are higher for tractor ploughed soils, the chances of maximum adhesion are more in ploughed soils than in virgin ones as Baver (1930) pointed out that maximum adhesion takes place at a moisture content fairly close to the upper plastic limit. The difference in plasticity of virgin and cultivated soils may have some relation to individual exchangeable bases (as discussed later on). Baver (1928) observed that calcium increases the plastic number whereas magnesium and potassium ions lower it. Our results are also in the same line. Tractor ploughed soils show higher plastic number as well as higher content of exchangeable calcium as compared to the virgin soils. With the increase in the amount of exchangeable magnesium and potassium, a corresponding decrease in plastic number is also observed. The sticky points for virgin soils range between 15 and 29 while for tractor ploughed soils, the values vary from 14 to 33. The tractor ploughed soils have higher values for stickly point than the virgin soils.

TABLE 3

Atterberg's constants

S. No.	Place	Type	Depth (in inches)	Upper Plastic Limit	Lower Plastic Limit	Plastic Number	Sticky Point
1	Bari	Virgin	0—12	55.0	22.0	33.0	29 7
2	,,	*Tr. Crop.	,,	60.8	23.0	37.8	33.7
3	,,	†Tr. Plug.	,,	61.8	23.7	38.1	33.4
4	,,	Virgin	12—24	53.0	20.0	33.0	38.6
5	,,	Tr. Crop.	,,	54.2	21.9	32.3	28.8
6	,,	Tr. Plug.	,,	54.3	21.4	32.9	29.6
7	,,	Virgin	0—12	29.11	15.76	13.35	19.76
8	,,	Tr. Plug.	,,	37.46	19.28	18.18	20.65
9	,,	Virgin	12—18	32.08	19.37	12.71	15.15
10	,,	Tr. Plug.	,,	33.19	20.77	12.42	14.81
11	Maliwara	,,	0—12	60.4	29.3	31.1	33.5
12	,,	,,	12—24	58.7	28.3	27.9	31.3
13	Salkanpur	Virgin	0—12	51.4	21.5	29.9	26.0
14	,,	,,	12—24	48.4	18.7	30.0	25.1
15	Obaidganj	,,	0—12	45.76	24.01	21.75	27.38
16	,,	,,	12—18	46.30	23.92	22.38	28.70

* Tractor ploughed and crop taken.
† Tractor ploughed.

Aggregate analysis : The results of aggregate analysis are given in table 4. The state of aggregation was calculated by using the equation proposed by Baver and Rhoades (1932). The state of aggregation is higher in virgin soils than in tractor ploughed soils. The degree of aggregation in virgin soils is more than that in the case of tractor ploughed soils; the range for virgin soil is between 41 and 56 per cent while for tractor ploughed soils, it is between 20 and 60 per cent. It is, thus, clear that degree of aggregation has been very much affected by tractor cultivation, so much so that in one case it has been reduced by nearly 50 percent. However, such difference is only prominent in surface soils whereas no such marked difference could be observed in the subsurface soil.

According to the conception of the structural coefficient, as postulated by Russell (1938), the structural coefficient is unity if the soils are perfectly aggregated whereas it is zero, if there is no aggregation at all. In the present calculations, the lower limit was taken as 0.05 mm. (Baver and Rhoades, 1932). The percentage of particles of the size (0.05 mm.) in mechanical analysis was obtained by plotting the log of vilocity of particles against their percentages. Studies on aggregate analysis here indicate that virgin soils are better aggregated than the tractor ploughed soils as virgin soils have higher structural coefficients than the virgin ones. Same inference is arrived at if the concept of Lutz, as quoted by Russel (1938), is used. The coefficient of aggregation (Retzer and Russell, 1941) is also fairly high for virgin soils than for tractor ploughed soils ; being 267.29 in virgin and 219.40 in tractor ploughed soils. The conclusion is the same as above that virgin soils are in a better state of aggregation as compared to the tractor ploughed soils.

All these observations point to one conclusion that tractor ploughing has a definite deterimental effect on the structural character of these soils and this is confirmed by the observation and experience of previous workers (Yodav, 1937 ; Olmstead, 1946 ; Clark and Marshall, 1947 ; Klingebiel and O'Neal, 1952). This property is brought out by the results of volume weight, permeability and porosity.

It can be said that tractor ploughing of these black soils affects the structure to a certain limit and how far it has got a bearing on the agronomical aspect can only be ascertained by detailed field experiments.

Chemical Properties of the Soils

As an adjunct to the study on changes in the physical properties of the soils under tractor ploughing, changes, if any, of chemical constituents, base exchange capacity and exchangeable bases, organic carbon and nitrogen of these soils were also taken up and reported below.

Chemical constituents : Data on the analysis of hydrochloric extract of the soils are presented in table 5. Results obtained do not manifest any effect of tractor ploughing on soils so far the chemical constituents are concerned.

Base exchange capacity and exchangeable bases : The total base exchange capacities of these soils are fairly high and are completely saturated with exchangeable bases, calcium and magnesium being the predominant. Virgin and tractor ploughed soils do not differ in their total base exchange capacities. The amounts of individual bases, however, are slightly different in virgin and ploughed soils. The exchangeable calcium is more whereas exchangeable magnesium and pottasium are less in tractor ploughed soils as compared to the corresponding virgin soils. The relationship of the individual exhangeable bases to some of the physical properties such as plastic number has been discussed earlier.

Data on water soluble salts, as presented in table 6, show that there is practically no difference in the amount of total soluble salts in virgin and tractor ploughed soils, indicating thereby that the content of total soluble salts will, in no way, affect the fertility status or physical condition of the soils. The concentration of salt is much below the danger limit.

Organic matter and C/N ratio : The amount of organic matter, as determined by Walkley & Black's method (Walkley, 1935), is considerably lower in the tractor ploughed soils than the virgin soils. Tractor ploughing to a depth of 12 inches might have helped to oxidise the organic matter at a much higher rate by exposing it to hot climate prevalent in this tract.

TABLE

Aggregate

Place Type Depth in inches Analysis	Bari Virgin 0—12 Agg.	U.D.	Bari Virgin 12—24 Agg.	U.D.	Bari Tra. Pl. Crop. 0—12 Agg.	U.D.	Bari Tra. Pl. Crop. 12—24 Agg.	U.D.	Bari Tract Pl. 0—12 Agg.	U.D.
size in particles in mm.										
2.0	3.76	—	1.02	—	0.9	—	2.90	—	5.14	—
2.0—1.5	7.20	—	1.74	—	0.94	—	0.39	—	8.61	—
1.5—1.0	9.00	—	5.82	—	2.62	—	0.69	—	12.04	—
1.0—0.5	9.77	—	12.54	—	5.93	—	5.94	—	14.25	—
0.5—0.2	24.10	—	26.39	—	37.34	—	43.0	—	19.61	—
0.2—0.1	14.98	—	14.30	—	19.22	—	14.17	—	11.57	—
0.1—0.05	10.02	—	16.28	—	12.77	—	8.21	—	4.76	—
.05	21.17	—	22.43	—	21.08	—	24.70	—	24.02	—
2— .2	—	0.70	—	0.63	—	0.68	—	0.68	—	1.88
0.2— .02	—	28.76	—	26.33	—	20.09	—	19.9	—	19.67
0.02—.002	—	17.36	—	23.24	—	19.64	—	19.80	—	20.10
.002	—	45.80	—	40.64	—	49.84	—	51.56	—	49.44
.05	79.83	35.0	77.97	35.0	79.72	38.4	75.3	37.5	75.98	38.5
State of aggregation		44.83		42.97		41.32		37.8		37.48
Degree of aggregation		56.1		55.7		51.8		50.2		49.3
Structure coefficient D—S/D		0.67		0.59		0.58		0.54		0.54
Structure coefficient		3.79		8.28		4.08		1.42		nil

Agg.—Aggregate
U D—Ultimate dispersion

4

analysis

Bari Tract. Pl. 12--24		Bari Virgin 0—12		Bari Trac. Pl. 0—12		Maliwara Tra. Pl. 0—12		Maliwara Tra. Pl. 12—24		Sultanpur Virgin 0—12		Sultanpur Virgin 12—24		Obaidul-laganj Virgin 0—12	
Agg.	U.D.	Agg.	U.D.	Agg.	U.D.	Agg.	U.D.	Agg.	U.D.	Agg.	U.D.	Agg.	U.D.	Agg.	U.D.
2.51	—	3.11	—	5.03	—	0.7	—	1.42	—	2.27	—	1.13	—	3.17	—
2.37	—	3.67	—	3.65	—	3.98	—	2.6	—	4.33	—	1.41	—	4.17	—
3.46	—	5.53	—	5.81	—	6.58	—	8.92	—	6.99	—	2.66	—	9.27	—
8.45	—	9.97	—	13.02	—	14.28	—	21.34	—	8.87	—	5.99	—	17.94	—
41.58	—	19.71	—	16.14	—	22.94	—	34.76	—	27.90	—	36.10	—	16.37	—
15.70	—	19.29	—	17.78	—	13.98	—	8.06	—	19.51	—	8.58	—	12.10	—
5.99	—	8.84	—	7.63	—	6.18	—	3.44	—	6.36	—	5.66	—	4.14	—
20.04	—	30.08	—	30.94	—	31.36	—	17.40	—	24.73	—	38.29	—	32.54	—
—	1.88	—	2.78	—	3.76	—	0.26	—	0.27	—	11.5	—	8.33	—	0.86
—	19.33	—	31.72	—	44.49	—	15.67	—	16.10	—	28.04	—	24.68	—	19.06
—	21.04	—	21.00	—	20.56	—	21.68	—	19.72	—	14.0	—	14.40	—	23.36
—	50.6	—	34.0	—	27.2	—	52.6	—	53.83	—	38.6	—	43.36	—	49.5
80.06	37.3	69.92	41.2	69.06	55.2	68.64	25.0	82.52	23.0	76.27	43.0	61.53	38.0	67.46	29.7
	43.76		28.72		13.86		43.64		59.54		33.27		23.53		37.76
	54.6		41.0		20.07		62.1		72.1		43.6		38.7		55.9
	0.64		0.39		0.24		0.53		0.77		0.50		0.20		0.48
	nil		7.67		nil		0.84		nil		nil		5.48		8.08

TABLE 5

Analysis of hydrochloric acid extract
(Percentage on oven-dry basis)

S. No.	Place	Type	Depth (in inches)	Acid insolubles	Alakli insolubles %	Acid solution silica	Alkali soluble silica	Total soluble silica	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	P_2O_5	% Loss on ignition
1.	Bari	Virgin	0—12	72.51	40.18	0.66	27.21	27.87	10.16	9.15	1.12	0.91	0.60	0.12	4.4
2.	,,	,,	12—24	73.55	41.42	0.67	29.18	29.85	10.05	10.12	2.15	1.37	0.54	0.11	3.0
3.	,,	*Tr. Crop	0—12	70.12	38.37	0.58	25.17	25.75	11.16	9.15	1.57	0.95	0.47	0.08	3.6
4.	,,	,,	12—24	72.91	39.75	0.63	27.26	27.89	11.27	8.92	1.92	1.06	0.43	0.07	4.9
5.	,,	†Tr. Plug	0—12	74.18	40.85	0.69	29.18	29.87	12.56	10.12	0.88	0.42	0.44	0.09	4.5
6.	,,	,,	12—24	75.56	42.19	0.70	30.26	30.96	10.21	9.15	0.89	0.41	0.40	0.08	5.5
7.	,,	Virgin	0—12	76.16	42.86	0.72	29.17	29.89	11.19	9.15	1.96	1.05	0.52	0.06	2.6
8.	,,	,,	12—18	77.19	43.00	0.78	29.65	30.43	10.15	9.16	2.12	1.32	0.61	0.06	3.0
9.	,,	Tr. Plug	0—12	74.44	41.25	0.68	29.18	29.86	10.51	10.25	1.23	0.85	0.57	0.08	1.2
10.	,,	,,	12—18	76.57	42.17	0.74	30.36	31.30	11.12	9.51	1.59	0.95	0.49	0.08	3.7
11.	Maliwara	,,	0—12	73.18	40.26	0.60	27.50	28.10	11.51	8.20	1.21	0.90	0.60	0.12	4.0
12.	,,	,,	12—24	74.21	41.31	0.40	28.00	28.40	10.12	9.16	1.73	1.02	0.43	0.11	4.5
13.	Salkanpur	Virgin	0—12	69.16	39.27	0.37	26.58	26.95	12.02	8.15	1.34	0.82	0.60	0.10	1.9
14.	,,	,,	12—24	71.25	36.16	0.59	28.52	29.11	11.19	9.22	1.42	0.95	0.57	0.09	2.4
15.	Obaidullaganj	,,	0—12	68.19	38.70	0.59	24.12	24.71	10.51	9.32	2.16	1.05	0.52	0.06	6.4
16.	,,	,,	12—18	69.36	38.96	0.60	25.32	25.92	10.26	8.97	2.32	1.11	0.59	0.06	6.5

*Tractor ploughed and crop taken.
†Tractor ploughed.

TABLE 6

Exchange capacity and exchangeable basis, pH, and total soluble salts .

S. No.	Place	Type	Depth (in inches)	Exchangeable bases (m.e./100g)				Exchange Capacity	pH	Total Soluble Salts
				Ca	Mg	K	Total			
1.	Bari	Virgin	0—12	31.60 *(70.46)	9.36 (20.80)	3.7 (8.22)	44.66	40.2	6.3	0.1142
2.	,,	Virgin	12—24	28.00 (70.00)	8.87 (22.17)	3.3 (8.25)	40.17	40.3	6.6	0.1142
3.	,,	Tractor ploughed Wheat taken	0—12	39.70 (83.25)	6.40 (13.34)	2.1 (4.37)	48.20	48.6	7.7	0.10
4.	,,	,,	12—24	43.60 (88.00)	4.81 (9.70)	1.8 (3.60)	50.21	47.5	7.5	0.10
5.	,,	Tractor ploughed	0—12	38.50 (79.18)	7.56 (15.75)	2.1 (4.37)	48.16	46.4	6.5	0.1131
6.	,,	,,	12—24	41.80 (84.00)	6.40 (12.80)	1.8 (3.60)	50.00	46.3	6.5	0.1132
7.	,,	Virgin	0—12	28.40 (84.40)	5.62 (16.75)	3.0 (9.08)	33.02	30.2	7.9	0.0791
8.	,,	,,	12—18	15.60 (61.53)	8.97 (33.88)	1.5 (5.77)	26.07	24.7	8.1	0.0838
9.	,,	Tractor ploughed	0—12	20.50 (74.06)	4.52 (16.36)	1.8 (6.92)	26.82	27.0	7.8	0.890
10.	,,	,,	12—18	26.30 (81.25)	4.62 (14.41)	1.5 (4.68)	32.42	30.5	8.0	0.0952
11.	Maliwara	,,	0—12	43.20 (82.69)	5.61 (10.39)	3.1 (5.95)	51.91	50.0	7.7	0.0951
12.	,,	,,	12—24	44.50 (80.54)	4.82 (9.26)	3.1 (5.94)	52.41	51.0	7.9	0.0962
13.	Salkanpur	Virgin	0—12	31.40 (83.75)	5.61 (15.14)	3.0 (8.12)	37.31	35.6	8.3	0.1142
14.	,,	,,	12—24	37.60 (90.36)	2.47 (5.95)	2.4 (5.71)	42.47	39.0	7.9	0.0953
15.	Obaidullaganj	,,	0—12	41.60 (83.42)	5.04 (10.28)	1.9 (3.80)	48.54	45.4	7.8	0.0967
16.	,,	,,	12—18	32.80 (82.52)	5.32 (11.81)	2.0 (5.00)	40.12	37.9	7.9	0.0992

*Figures in bracket indicate % saturation with base in each case.

The fact that cultivation results in depletion of organic matter is confirmed by number of workers (Jenny, 1933; Metzer and Hide, 1938). Tractor ploughing has, thus, degraded these soils by diminishing their humus content by accelarating the rate of oxidation of organic matter.

Total nitrogen is considerably less in tractor ploughed soils than in virgin soils. The C/N ratios do not show much difference in the two types of soils.

TABLE 7

Organic carbon and nitrogen

S. No.	Place	Type	Depth (inches)	Organic Carbon %	Total N %	C/N ratio	Organic matter %
1.	Bari	Virgin	0—12	0.670	0.0866	7.80	1.15
2.	,,	*Tr. Crop	,,	0.615	0.0658	9.34	1.06
3.	,,	†Tr. Plug	,,	0.300	0.0448	6.70	0.52
4.	,,	Virgin	12—24	0.555	0.0714	7.70	0.96
5.	,,	Tr. Crop	,,	0.435	0.0504	8.63	0.75
6.	,,	Tr. Plug	,,	0.450	0.0406	11.11	0.78
7.	,,	Virgin	0—12	0.435	0.0686	6.33	0.75
8.	,,	Tr. Plug	,,	0.300	0.0588	5.10	0.52
9.	,,	Virgin	12—18	1.200	0.0686	17.50	2.06
10.	,,	Tr. Plug	,,	0.650	0.0350	18.80	1.11
11.	Maliwara	,,	0—12	0.825	0.0854	9.65	1.42
12.	,,	,,	12—24	0.885	0.0728	12.01	1.52
13.	Salkanpur	Virgin	0—12	0.870	0.0616	14.14	1.50
14.	,,	,,	12—24	0.555	0.0616	9.00	0.96
15.	Obaidganj	,,	0—12	0.975	0.0770	12.60	1.67
16.	,,	,,	12—18	0.945	0.0686	13.70	1.62

*Tractor ploughed and crop taken.
†Tractor ploughed.

TABLE 8

Total bacterial count (Dilution 1/100000).

Sl. No.	Place	Type	Plate No. 1	2	3	4	5	Mean	S. E. Mean	Remarks	pH
			No. of micro-organisms per gm. of soil					Average No. of micro-organisms per gm. of soil			
1.	Bari	Virgin	20	30	28	20	27	25.0+	2.33	Significant at 5% level	6.3
2.	,,	*Tr. Plug.	30	26	35	35	41	33.4 –	2.33		6.6
?.	,,	Virgin	20	30	28	20	27	25.0+	2.05	Significant at 1% level	6.3
4.	,,	†Tr. Crop.	50	47	46	53	41	47.4 –	2.05		7.7
5.	,,	Virgin	50	45	40	52	32	43.8+	8.77	Insignificant	7.9
6.	,,	Tr. Plug.	40	45	40	45	48	43.6 –	8.77		7.8

*Tractor ploughed and crop taken
†Tractor ploughed.

TABLE 9

Nitrogen fixing power

S. No.	Place	Type	Total N (in mg.) fixed per gm. of mannite
1.	Bari	Virgin	10.92
2.	,,	Tractor ploughed crop taken	10.22
3.	,,	Tractor ploughed	8.96
4.	,,	Virgin	9.24
5.	,,	Tractor ploughed	8.82
6.	Maliwara	Tractor ploughed	9.81
7.	Salkanwara	Virgin	11.06
8.	Obaidullahganj	Virgin	9.52

BIOLOGICAL PROPERTIES OF THE SOILS

Total bacterial count: Data presented in table 8 show that total count is significantly higher in tractor ploughed soils than in virgin soils. In case of samples which were collected soon after tractor ploughing, the increase in number of bacteria is not significant. Due to ploughing, the sub-soil was brought at the top. The sub-soil is known to contain less number of organisms and time might not have been sufficient for multiplication unlike the samples which were collected a month or two after the ploughing was done.

Nitrogen fixing power and nitrifying capacity: Data on nitrogen fixing power show that there is a tendency towards the reduction in nitrogen fixing power in tractor ploughed soils whereas reverse is the case with nitrification. In the case of samples which were collected soon after tractor ploughing, nitrifying power is more in virgin than in ploughed soils.

SUMMARY

Work has been conducted on Block Cotton Soils of Bhopal State to study the likely changes in its physical, chemical and biological properties, due to the introduction of tractor cultivation.

A comparative study of the virgin and tractor ploughed soils reveals that the mechanical composition is unaffected, whereas the structural condition is affected as is evidenced by the permeability, porespace, volume-weight and the distribution of water stable aggregates. The virgin soil has shown less susceptibility to erosion as indicated by dispersion and erosion ratios.

Tke nutrient status, as judged by HCl soluble constituent and base exchange capacity and exchangeable bases, remains unaffected. However, there is a lowering of the organic matter content and total nitrogen.

The biological activity is found to be more in virgin soils than in tractor ploughed soils as indicated by total count, nitrogen fixing power and nitrifying power.

In general, it may be said that while the chemical and biological properties remain unaffected, the physical properties especially the structure and other related properties are affected due to tractor ploughing as compared with virgin soil, and similar changes are also brought about by normal practice of cultivation.

TABLE 10

Nitrifying power of soils in liquid media (Omenliasky & Winogradsky Sol. No. 1 & No. II)

(N as NO_2 and NO_3 per 100 c.c. Media)

Sl. No.	Place	Type	First Week				Second Week				Fourth Week				Eighth Week			
			Solution No. I		Solution No. II		Solution No. I		Solution No. II		Solution No. I		Solution No. II		Solution No. I		Solution No. II	
			NO_2	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2	NO_3
1	Bari	Virgin	0.162	Tr.	3.24	0.4	0.624	Tr.	4.86	0.5	2.43	Tr.	2.43	Tr.	Tr.	4.0	Tr.	10.0
2	„	Tractor ploughed and crop taken	0.129	„	6.48	0.2	0.499	„	3.24	0.7	2.43	„ „	2.43	„	„	5.0	„	15.0
3	„	Tractor ploughed	0.077	„	8.10	0.4	0.624	„	3.24	0.4	2.43	„	3.24	„	„	4.0	„	15.0
4	„	Virgin	0.012	„	8.10	0.6	0.624	„	32.4	0.5	2.43	„	2.43	„	„	3.0	„	10.0
5	„	Tractor ploughed	0.038	„	6.48	0.2	0.988	„	4.86	0.5	2.43	„	3.24	0,5	„	2.0	„	6.0
6	Maliwara	„	0.378	„	5.18	0,3	1.872	„	4.86	0.6	3.24	„	0.162	0.3	„	4.0	„	8.0
7	Sulakanpur	Virgin	0.129	„	6.48	0.4	1.248	„	4.86	0.4	2.43	„	2.43	Tr.	„	3.0	„	10.0
8	Obaidullaganj	„	0.018	„	3.24	0.4	0.624	„	3.24	0.5	2.43	„	2.43	0.5	„	2.0	„	6.0

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The Mobility Ratios of Clay Membrane Electrodes

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The method of using mineral membranes for the determination of mono - and bi-valent cations present singly in solution was initiated by Marshall and his co-workers (1949). Since 1941, the continued use of the membrane electrodes prepared from montmorillonitic clays by Marshall and his associates (*loc. cit.*), Chatterjee (1949), and Mitra (1954) has established the technique as an effective means of determining cationic activities. For this purpose, the montmorillonitic clay suspensions are allowed to form thin membranes by slow evaporation. Heat treatment ranging from 400° to 700°C improves the electrochemical as well as the mechanical properties of the membranes. The clay surface becomes reversible with respect to cations in solutions by virtue of its exchange properties. These clay membrane electrodes, unlike glass electrode which measures only the H-ion activity, are not usually specific for any particular cation, but are often less specific for H-ions than others, *viz.*, Na, K, Ca, Mg, etc. If such a membrane electrode separates two solutions having different cationic activities, the e.m.f. observed should be equal to that calculated by means of the Nernst equation, provided the membrane electrode is perfectly reversible. Working with a large number of clay membrane electrodes, it has been found (Mitra, 1954) that they can usually measure ionic activity of no more than 0.1 molal solutions in the case of monovalent cations and 0.01 molal in the case of bivalent cations.

The activity of single cations, either mono - or bi-valent, in a true solution or in a colloidal suspension can be easily determined but not so in the case of a mixture of cations. Marshall and Bergman (1941) approached the problem by using specific membranes which are sensitive to one kind of cation in presence of the other. As we know very little about the conditions necessary for the preparation of specific membranes, they may be obtained only by the process of trial and error. The usual approach is to characterise the membrane by (*i*) the charge on the membrane surface, and (*ii*) the mobility ratio of the cations (see below). The wider this ratio is, the greater is the chance of the membrane being specific.

The present paper is primarily concerned with the preparation and standardisation of the membranes, and the evaluation of the mobility ratios for selected pair of cations from amongst Na, K, Ca and Mg ions. Before determining the mobility ratios, the membranes must be tested as to the ranges of obedience to the Nernst equation. The membrane electrodes, for this purpose, are generally separated by solutions of electrolytes having different activities of the same cations. The ranges within which the observed e.m.f. agrees well with that calculated by means of the Nernst equation are noted for each cation. While measuring the mobility ratio of a pair of cations the activities of the cations concerned must remain within the ranges of the individual cations. The mobility ratios are calculated by means of the following relationships.

$$E=\frac{RT}{F}\ \ln\ \frac{a_K}{a_{Na}}\cdot\frac{U_K}{U_{Na}} \qquad \cdots \quad (I)$$

$$E=\frac{RT}{2F}\ \ln\ \frac{a_{Na}}{2\frac{U_{Ca}}{U_{Na}}\cdot a_{Ca}} \qquad \cdots \quad (II)$$

$$E=\frac{RT}{2F}\ \ln\ \frac{a_K}{2\,\frac{U_{Ca}}{U_K}\,.\,a_{Ca}} \qquad \ldots \quad \text{(III)}$$

Where E is the observed e.m.f.. & a's and U's are the respective activities and mobilities.

MATERIAL AND METHOD

Thin membranes were obtained by evaporating clay suspensions of either H-or Ca-saturated montmorillonitic clays isolated from a Padegaon soil, a Chinsura soil, and Aquagel (Mitra, 1954). They were then cut in proper sizes and heated to the desired temperatures for a period of 24 to 48 hours in an electric furnace. Prepared in this way, the membranes are expected to attain the desired electrochemical properties. To test this, one end of a small 3 in. pyrex glass tubing is flanged and the membrane is fixed to this end by means of Durofix. The membrane is then tested for asymmetry potential, if any, by placing solutions of the same cationic activity on each side and measuring the potential difference by means of a Cambridge potentiometer and L & N Galuanometer. Those membranes which showed zero or negligible asymmetry potential were used to find out the range of validity of the Nernst equation, and also the mobility ratios of cation pairs (*cf.* above).

RESULTS AND DISCUSSION

The mobility ratios $\frac{U_{Ca}}{U_{Na}}$, $\frac{U_{Ca}}{U_K}$ and $\frac{U_K}{U_{Na}}$ calculated from the above relationships are given in table 1. It will be noticed from these data that the mobility ratios for a particular membrane and with a particular pair of cations depend on the activity range of the cation pairs studied. The variation is not, however, regular. But it is possible to choose a few membranes whose mobility ratios remain fairly constant over a particular range of activities. Only random search for such membrane is possible. Once the membranes conform to the requirements, they are found to perform well for quite a long time.

The alternative expression to mobility ratio, termed by Marshall (1948) as the differential heat of adsorption of cations, has a limited significance insofar as it is not known whether the exchange reaction is independent of temperature. If, however, the membrane is considered, in the limited range of validity of the Nernst equation, as a cation reversible electrode, then the observed e. m. f. may be expresed as the difference between the e. m. f. of each element of the cell.

For example, in the cell,

$$\begin{array}{c|c} a_{Na} & a_K \\ E_1 & E_2 \end{array}$$
membrane

$$E_{Obs}=E_2 \ -E_1 \ =(E^0_K-E^0_{Na})-0.059\log\frac{a_K}{a_{Na}}$$

$$\begin{array}{c|c} a_{Na} & a_{Ca} \end{array}$$
membrane

$$E_{Obs}=(E^0_{Ca}-E^0_{Na})-0.059\log\frac{a_{Ca}^{\frac{1}{2}}}{a_{Na}}$$

Therefore, from the observed values of e. m. f. and known activities of the cation pairs the difference between the E^0's may be evaluated. This has been done for the pairs : Ca/K, Ca/Na and K/Na. It is obvious that $(E^0_{Ca}-E^0_K)-(E^0_{Ca}-E^0_{Na})$ must be equal to $E^0_{Na}-E^0_K$, which can be obtained directly. The results of these calculations given in table 2 (columns 4 and 6) show that the agreement is fairly close. It is to be pointed out that the comparison must preferably be done, as far as possible, at the same activity ranges of the cations. Columns 5 and 7 of table 2 show that this condition has been fulfilled so far as the recorded data in table 1 are concerned.

TABLE 1

Mobility ratios of cations

Membrane					
	a_{Ca}	0.0003	0.0027	0.0081	
	a_{Na}	0.00097	0.00877	0.0263	
Pad. Ca. 600°C (C)	U_{Ca}/U_{Na}	0.94	1.36	1.12	
	$E^{\circ}_{Ca, Na}$	146.9	49.0	21.5	
Pad. Ca. 600°C (G)	U_{Ca}/U_{Na}	0.90	1.26	1.49	
	$E^{\circ}_{Ca,Na}$	147.9	52.0	29.3	
Pad. Ca. 600°C (67)	U_{Ca}/U_{Na}	0.94	0.88	1.05	
	$E^{\circ}_{Ca,Na}$	147.1	30.0	20.3	
Membrane					
	a_K	0.009	0.027	0.081	0.081
	a_{Na}	0.00877	0.0262	0.0263	0.0789
Pad. Ca. (600°C (C)	U_K/U_{Na}	1.79	1.95	1.88	
	$E^{\circ}_{Na,K}$	14.9	17.1	16.5	
Pad. Ca. 600°C (G)	U_K/U_{Na}	1.44	1.54	1.22	
	$E^{\circ}_{K,Na}$	8.9	11.1	5.1	
Pad. Ca. 700° (67)	U_K/U_{Na}	2.32	2.46	2.55	2.68
	$E^{\circ}_{Na,K}$	21.6	23.1	24.0	25.3

TABLE 1 (*contd.*)

Membrane								
	a_{Ca}	0.0081	0.0081	0.0027	0.0003	0.0009	0.0027	0.0027
	a_K	0.081	0.027	0.009	0.001	0.009	0.081	0.027
Pad. Ca. 600°C (C)	U_{Ca}/U_K	1.89	1.10	1.04	.60			
	$E^{\circ}_{Ca,K}$	35.9	41.4	57.1	46.7			
Pad. Ca. 600°C (G)	U_{Ca}/U_K	2.02	1.13	0.86	0.52			
	$E^{\circ}_{Ca,K}$	25.1	40.8	61.9	43.1			
Pad. Ca. 700°C(67)	U_{Ca}/U_K	1.32	.98	1.03	0.90	1.54	1.78	1.53
	$E^{\circ}_{Ca,K}$	36.4	44.6	51.9	51.5	54.0	42.4	47.1

TABLE 2

Membrane	$E^o_{Ca} - E^o_K$ (a)	$E^o_{Ca} - E^o_{Na}$ (b)	Difference (a - b)	a_{Ca}/a_{Na} or a_K	$E^o_K - E^o_{Na}$ (Obs)	a_K/a_{Na}
Pad. Ca. 600°C (C)	41.4	21.5	19.9	$\frac{.0081}{.027}$	17.1	$\frac{.028}{.0263}$
Pad. Ca. 600°C (G)	40.8	29.3	11.5	$\frac{.0081}{.0263}$	11.1	,,
Pad. Ca. 700°C (67)	44.6	20.3	24.3	,,	32.1	,,
Pad. Ca. 600°C (C)	57.1	42.2	14.9	$\frac{.0027}{.009}$	14.9	$\frac{.009}{.00877}$
Pad. Ca. 600°C (G)	61.9	52.0	9.6	$\frac{.0027}{.00877}$	8.8	,,
Pad. Ca. 700°C (67)	51.9	30.0	21.9	,,	21.6	,,

SUMMARY

Na, K and Ca-ion reversible electrodes were prepared from three montmorillonitic clays by heating thin membranes to the desired temperatures. After ascertaining the range by obedience of these electrodes to the Nernst equation, they were employed for the determination of the mobility ratios of the cation pairs, Na/K, Na/Ca and K/Ca. For this

purpose the membranes were interposed between solutions of the respective chlorides keeping their activities within the valid range of the Nernst equation. Considering the electrodes as cation reversible each surface of the membrane may be considered as a single electrode whose potential may be expressed as a function of the activity of the cation in contact with it and a standard electrode potential, E°. The difference between the E°'s has been evaluated from measurement of the e.m.f of a cell constituted of the membrane interposed between solutions of known cationic activities. It has been found that the differences between E^{o}_{Ca} -E^{o}_{K}, E^{o}_{Ca} -E^{o}_{Na} and E^{o}_{Na}-E^{o}_{K} mutually agreed within the experimental error.

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Lime Requirement of an Acid Sandy Soil

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The distribution of acid soils is fairly extensive in Bihar. They are mostly found in the uplands of the hilly areas of the State. These soils are old and sedentary from which bases have leached down to a very great extent, rendering them acidic. Soils of alluvial tracts of Bihar, on the other hand, are either neutral or alkaline in reaction. But, there are huge stretches of alluvial soils in the north eastern corner of the State that are sandy to sandy loam in texture, fairly acidic in reaction and support very little crop farming. An area of 4000 acres, situated on such lands lying waste at Islampur in the district of Purnea, was acquired by the Govt. of Bihar in 1950 for crop production and the authors were asked to advise the Govt. on the management of the soils of the farm.

The surface soil of the farm was found to be sandy loam in texture which extend up to a depth of 15 to 20 inches below which a continuous layer of coarse sand is found. The chemical and mechanical analyses of the soil, sampled from different locations of the farm revealed, on an average, the following characteristics (Mukherji and Mandal, 1952) :—

Moisture 2.20%; Organic matter 5.8%; Clay 14.8%; Silt 17.0%; Fine sand 56.3%; Coarse sand 3.5%; Insoluble silica 73.8%; Soluble silica 0.9%; Sesquioxides 8.7%; CaO 0.2%; K_2O 0.3%; P_2O_5 0.05%; N 0.2%; Available P_2O_5 0.02%; Available K_2O 0.007%; Cation exchange capacity-10.4 m.e%; Exchangeable Ca-1.4 m.e%; Exchangeable Mg-0.7 m.e%; Exchangeable K 0.5 m.e%; pH of the soil is 5.3.

Prior to the detailed examination of the soil chemically, some cropping tests were made by the local farm management and it was observed that the soils supported no crop growth worth mentioning excepting rice which, too, was a rather poor crop. Thus, it was thought necessary to try a few experiments with various plant nutrients *e.g.*, N,P,K, Mg, Mn, Cu, Zn, B *etc.*, as well as some liming experiments in the farm.

In the present paper, only the results of liming experiments carried out in 1951 and 1952 have been reported. These experiments could not be carried out further due to the sudden closing of the farm for the rehabilitation of refugees from East Pakistan in 1953.

MATERIAL AND METHOD

In estimating lime needs of an acid soil, the amount of lime to be added, proper time of applying lime to the soil and the frequency of liming have to be considered. Field experiments were, therefore, set up on a representative soil of the farm with moderate doses of lime applied in two different periods of the year. Another experiment was also laid down with high amounts of lime in order to find out the exact amount of lime that would raise the pH of the soil to a point optimum for crop growth.

Jainti lime containing 30% calcium was used throughout and the treatments in different experiments were as follows :—

I (*a*) Moderate liming before rains; (*b*) Moderate liming after rains.

Treatments :-

(1) No lime.
(2) 300 lb. of $CaCO_3$ (equivalent to 5 md. or 3.6 cwt. of Jainti lime) per acre.

(3) 600 lb. of $CaCO_3$ (equivalent to 10 md. or 7.2 cwt. of Jainti lime) per acre.
(4) 900 lb. of $CaCO_3$ (equivalent to 15 md. or 10.8 cwt. of Jainti lime) per acre.
(5) 1200 lb. of $CaCO_3$ (equivalent to 20 md. or 14.4 cwt. of Jainti lime) per acre.
(6) 1500 lb. of $CaCO_3$ (equivalent to 25 md. or 18.0 cwt. of Jainti lime) per acre.

II. Heavy liming before rains.

Treatments :-

(1) No lime.
(2) 1700 lb. of $CaCO_3$ (equivalent to 1 ton of Jainti lime) per acre.
(3) 3400 lb. of $CaCO_3$ (equivalent to 2 tons of Jainti lime) per acre.
(4) 5100 lb. of $CaCO_3$ (equivalent to 3 tons of Jainti lime) per acre.
(5) 8500 lb. of $CaCO_3$ (equivalent to 5 tons of Jainti lime) per acre.

Experiments I(*a*) and I(*b*) were laid out in 1951 in 1/80th acre subplots while experiment II was laid out in 1952 in 1/40th acre sub-plots and in each case, the treatments were randomized and replicated four times. In the first year (1951), rice and barley were grown in I (*a*) and I (*b*) respectively. The rice crop was very poor due to extreme drought conditions prevailing in the month of August and also due the fact that the crop was sown without applying other nutrients (*e. g.* N,P,K) to the soil. Further, as the experimental plots were not fenced, stray cattle grazed on the barley crop in I (b) in one night in December and thus the yield data were not recorded treatment-wise. Next year (1952) fresh additions of lime were made in Expt. I (*a*) and rice was grown again. Maize was grown in I (*b*). This was a year of good rainfall and the experimental plots were fenced and no damage was done to the crop from any extraneous source. In Expt. II (heavy liming experiment), lime was applied in June. It was decided to grow maize and wheat in this experiment. But as it was late for maize, its cropping was abandoned and the land remained fallow during rains. In the following *rabi* season, wheat was sown. In each case, a basal dressing of N,P,K, was given at the rates of 40 lb. of N, 40 lb. of P_2O_5 and 40 lb. of K_2O per acre in 1952.

Soil samples were collected about six months after liming from experiments I (*b*) and II and after four months from experiment I (*a*) and their pH and degrees of calcium saturation were determined. In the laboratory, a parallel experiment was set up for the heavy liming series with the same soil as in the field experiment, on lines suggested by Dunn (1943) in order to find out the relationship between the field and laboratory results. In the laboratory studies it was found more convenient to add saturated solution of $Ca(OH)_2$ in lots equivalent to 1500, 3000, 4500 and 6000 lb. per acre.

The pH was determined with the help of a Muir-head pH meter using glass electrodes and the degree of calcium saturation by leaching the soil with neutral normal ammonium acetate. Soils brought to equilibrium in the laboratory with $Ca(OH)_2$ were filtered and washed with small quantities of alcohol to remove any excess of $Ca(OH)_2$ and leached with ammonium acetate.

RESULTS AND DISCUSSION

The effects of applying moderate doses of lime in two different seasons are given in table 1.

TABLE 1

Changes of pH and degree of calcium saturation with liming at moderate doses and their relationship to crop yields

Sl. No.	Treatment $CaCO_3$ per acre	Lime applied before rains				Lime applied after rains				
		pH		Degree of calcium saturation	Yield of rice in md. acre	pH		Degree of Calcium saturation (after 6 months)	Yield of maize	
		1951	1952			6 months after liming	12 months after liming		Grain	Stalk
1	None	5.15	5.30	16.70	24.7	5.30	5.20	15.70	2.56	50.00
2	300 lb.	5.35	5.40	19.20	26.5	5.55	5.40	16.20	3.98	59.00
3	600 lb.	5.50	5.80	20.70	20.5	5.70	5.45	18.50	5.44	70.00
4	900 lb.	5.65	5.90	21.30	24.0	5.90	5.70	21.40	4.10	70.70
5	1200 lb.	5.85	6.00	24.10	25.4	6.10	5.90	25.90	6.80	73.30
6	1500 lb.	6.05	6.20	27.80	24.4	6.20	6.05	30.20	6.10	84.70

Critical difference of mean yield at 5%........ .... 2.24 7.64

In the heavy liming experiment, the wheat crop grew well initially but the grain setting was retarded due to the blowing of dry west wind untimely. Consequently, almost negligible yields of grains were obtained and thus the yield of wheat straw only has been reported in table 2.

TABLE 2

Changes in pH and degree of calcium saturation effected by heavy applications of lime and their relationship to crop yields

Sl. No.	Liming under field conditions				Laboratory equilibrium studies		
	Treatments $CaCO_3$/acre	pH	Degree of calcium saturation	Yield of wheat straw in md. per acre	Treatment $CaCO_3$/acre	pH	Degree of calcium saturation
1	None	5.20	16.10	19.70	None	5.20	16.80
2	1700 lb.	6.20	34.90	28.80	1500 lb.	5.70	23.10
3	3400 lb.	6.60	48.30	27.40	3000 lb.	6.30	50.00
4	5100 lb.	6.85	55.70	27.90	4500 lb.	6.60	61.30
5	7500 lb.	7.05	72.30	29.60	6000 lb.	6.80	76.30

Critical difference of mean yield at 5%..............6.4

It is evident from tables 1 and 2 that Islampura soil requires liming at the rate of 1700 lb. of $CaCO_3$ or 1 ton of Jainti lime per acre in order that its pH may be raised by 1 unit, from 5.2 to 6.2. Results of experiments with different plant nutrients, not reported here (Mukherji, 1952), in which lime at the rate of 1 ton per acre was included as a treatment in a number of experiments also corroborate this finding.

It may also be noted from table 2 that the same amount of lime raises the pH by 0.4 units from pH 6.2 to 6.6 and by only 0.25 unit from pH 6.6 to 6.85. Such increments were effected by smaller additions of lime at lower pH values of the soil *e.g.* 5.4 (Table 1). Thus the rate of rise of pH due to liming should be considered only in relation to the initial reaction of the soil.

With smaller additions of lime (300 lb. of $CaCO_3$ per acre), the increase in the degree of calcium saturation was found to vary from 0.5% to 4.3%. With heavier additions (1700 lb. of $CaCO_3$ per acre), the variation was from 7.4% to 18.8%. Again, with 2 tons of lime or 3400 lb. of $CaCO_3$ per acre, the calcium saturation of the soil increased from 16.1% to 48.3%. For successful plant growth, Peech and Bradfield (1948) have recommended 60% calcium saturation of the soil. The yields of maize and wheat, given in tables 1 and 2, however, indicate that raising the pH beyond 6.2 or the degree of calcium saturation beyond 35% may not be of much avail for these crops at Islampur.

But since in a liming programme, maintenance of a good calcium status and favourable soil reaction are quite important considerations and since pH 6.5 has generally been regarded as optimum soil reaction for the growth of most of our upland crops *e.g.* wheat, maize *etc.*, liming at the rate of 2 tons per acre may be recommended for these soils which would raise the pH to about 6.6. This would also increase the degree of calcium saturation to about 48%, thus providing sufficient margin for many other crops demanding higher calcium saturation of the soil. Liming has also to be recommended in accordance with the calcium needs of the crops grown. From the yields of three different crops given in tables 1 and 2, it seems that maize is the most responsive and rice the least responsive amongst the crops studied here. The results of experiments with various other plant nutrients also indicate that the rice crop would not ordinarily respond to liming at Islampur (Mukherji, 1952).

For Islampur, the time of application of lime should preferably be after the monsoon. Comparing the increases in the degree of calcium saturation on account of liming at the rates of 1200 and 1500 lb. of $CaCO_3$ per acre, it seems that there is a likelihood for greater retention of calcium by the clay, if lime is applied after the rains. This may be explained if the high monsoon rainfall (100—120 in.) and the sandy nature of the soil at Islampur be taken into consideration when considerable amounts of calcium are likely to be leached down. A reference to table 1, however, indicates that the monsoon rains have caused a reduction in the pH by 0.2 unit only in one season. Thus, if lime be applied initially at the rate of 2 tons per acre raising the pH of the soil to about 6.5, then no liming need be done for the next two years at the end of which period the pH may drop to about 6.1 or so. Application of lime at the rate of 1 ton per acre at this stage *i.e.*, on the third year should again raise the pH to about 6.5. In spite of the high cost of lime (Rs. 40/- to Rs. 45/- per ton) and high transportation charges, such a practice is likely to prove quite economical.

Laboratory equilibrium studies indicate that for higher doses of liming the field and laboratory data are fairly comparable, in general, in spite of variations between some individual doses. **Thus the liming factor for Islampur may be fixed at 1.0.**

SUMMARY

Lime requirement of an acid sandy soil (pH 5.2) has been worked out as a result of field and laboratory studies.

It was found that application of lime containing 30% calcium at the rate of 2 tons per acre, initially followed by 1 ton of lime every third year, would maintain the pH of the soil at levels ranging between 6.0 and 6.5 and the calcium saturation of the clay between 30% and 50%. There are indications that higher or more frequent applications would neither be economical nor commensurate with crop yields. Rice did not respond to liming.

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The Effect of Irrigation on the Microbiological Changes of the Rainfed Black Soils of Rayalaseema

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The Tungabhadra project area consists of an extensive area of black soils. They are clayey, extending to a depth of two to eight feet. The gypsum concretions are found in some types. Wherever gypsum is found, a zone of salt concentration is observed in lower horizons. All these soils have a porous layers of partially weathered rock called locally *garusu* in the lower depths. The soils of this area are poor in nitrogen (varying from 0.029 to 0.041%) and organic matter. They have high base exchange capacity, lime content, and retentivity for moisture, but low percolation and seepage capacity (Ramiah, 1937). The black soils in Neera Valley in Bombay State, became saline a few years after the advent of irrigation. Similar fear was felt before sanctioning the scheme. To test the irrigability of the black soils of Tungabhadra area, Agricultural Research Station was started in 1939 at Siruguppa, Bellary District, which is a typical black soil area. Though the agronomic experiments coupled with chemical investigations provide a reliable information, they are, however, laborious and time consuming. A quicker method of determining the fertility status of soil during the post-irrigation period may be used with considerable advantage. Microbiological method would undoubtedly throw some light on this problem (Hiltner and Stormer, 1903 Workman, 1922). The trend of microbiological changes, population and activity in the soils under different treatments, moderate and heavy type of irrigation, manured and unmanured, and kept under cultivated fallow conditions, were estimated systematically to determine whether the soil fertility was deteriorating on the advent of irrigation due to rise of salt to the top foot.

EXPERIMENTAL

Samples were drawn from 1940 onwards from the four blocks of fields from the Agricultural Research Station, Siruguppa (Bellary district), comprising both the pre-irrigation and post-irrigation soils. The treatment given to blocks were as below :—

Block Number	*Treatment*
III	No manure-cultivated.
V	Heavy irrigation. Wet method of cultivation.
VII	No cultivation (fallow) but weeds were removed by passing Guntaka (blade harrow) and left in the field.
VIII	Garden cultivation (Medium irrigation).

The pre-irrigation samples were taken before any operations began and later samples were drawn at the end of each cropping season. Samples were drawn up to one foot, adhering strictly to all the precautions laid down for drawing bacteriological samples under aseptic conditions. Five samples from the different parts of the field were drawn and made into a composite samples for each treatment.

The samples were analysed soon after receipt. The total count was estimated by the standard plate method using sodium albuminate agar which gives fairly accurate

comparable values. Incubation was done at 28°C and counts made at the end of 48 hours and the final counts taken at the end of 72 hours. Carbon dioxide evolution was estimated by Waksman and Starkey's (Waksman and Starkey, 1924) method.

RESULTS AND DISCUSSION

The physical properties of the soils of the Tungabhadra project area are given in table 1. Their pH value varies from 8.03 to 9.26. The total water soluble salts are given in table 3, and the rainfall data in table 2. The average rainfall was 24.89 inches in 39 days. The total microbial population is given in table 4. The same is presented in Fig. 1. The microbial activity as measured by the evolution of carbon dioxide is given in table 5 and graphically in Fig. II.

TABLE 1

Physical characteristics of the different types of soils (first foot) met with in the Project area

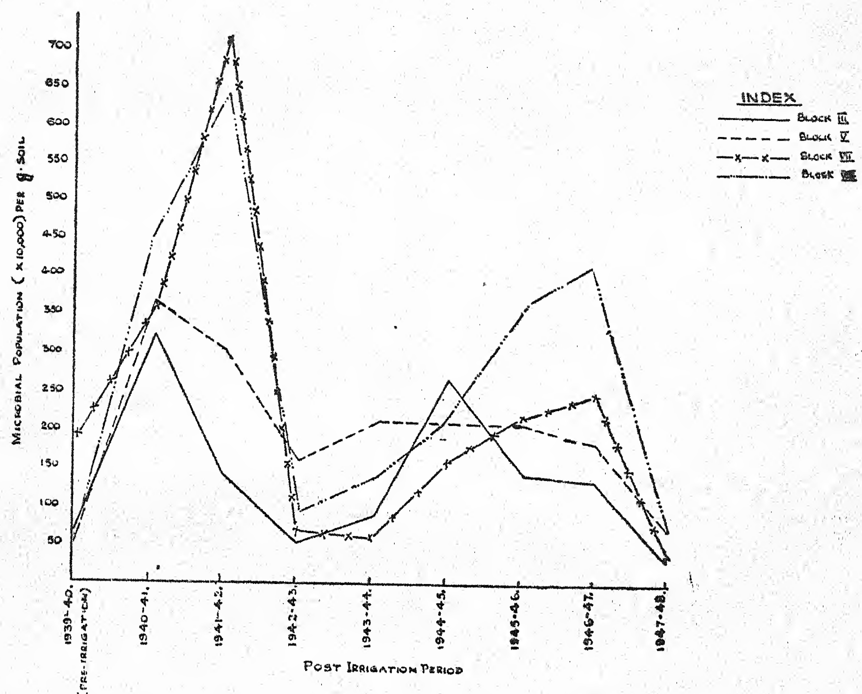
(Per cent on oven-dry basis.)

Nature of the soil	Salt content	Clay plus silt	Coarse & fine sand	Hygroscopic co-efficient	Water holding capacity	Pore space	Absolute specific gravity
1. Deep black soil (with gypsum	0.08	68.1	24.0	8.0	74.1	69.3	1.71
2. do. (No gypsum)	0.06	69.6	20.8	8.7	68.3	58.5	1.65
3. Shallow black soil (with gypsum)	0.11	62.1	30.9	7.1	74.3	65.1	1.69
4. do. (without gypsum)	0.06	67.7	22.4	8.0	66.7	58.6	1.63
5. Mixed	0.05	52.7	43.8	3.9	49.6	50.5	1.78

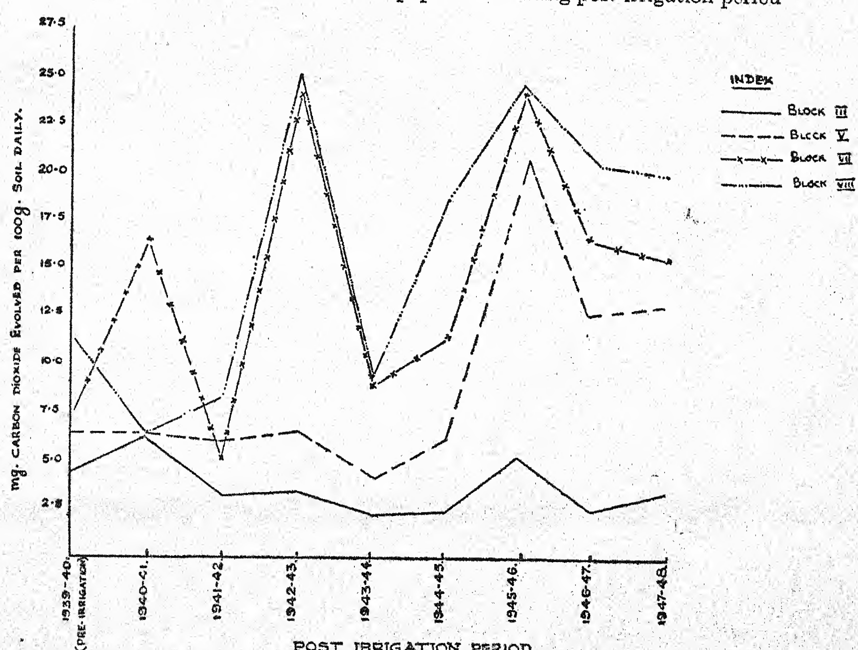
TABLE 2

Rainfall in inches during the period of experiment

Year	Rain in inches	No. of days	Remarks
1939-40	21.34	31	Long drought
1940-41	24.77	45	Favourable season
1941-42	21.14	36	Uneven rainfall
1942-43	16.92	31	do
1943-44	24.55	44	do
1944-45	30.60	42	—
1945-46	18.77	32	Well distributed
1946-47	18.27	36	do
1947-48	23.69	44	...



Graph I. Changes in microbial population during post-irrigation period



Graph II. Changes in microbial activity during post-irrigation period

TABLE 3

Total water-soluble salts of the first foot in soils receiving irrigation

Year		Block V	Block VIII
1939	Pre-irrigation	0.165	0.058
1940	Post-irrigation	0.099	0.058
1941	"	0.106	0.048
1942	"	0.101	0.057
1943	"	0.102	0.073
1944	"	0.091	0.088
1945	"	0.076	0.056
1947	"	0.082	0.067
1948	"	0.083	0.084

TABLE 4

Changes in microbial population due to irrigation of rainfed soils

Year	Block III No manure	Block V Wet cultivation	Block VII Fallow	Block VIII Garden cultivation
Pre-irrigation 1939-40	694,000	656,000	1,209,000	571,000
Post-irrigation				
1940-41	3,350,000	3,750,000	3,640,000	4,590,000
1941-42	1,500,000	3,130,000	7,250,000	6,550,000
1942-43	550,000	1,750,000	660,000	1,020,000
1943-44	1,010,000	2,150,000	550,000	1,550,000
1944-45	2,920,000	2,200,000	1,650,000	2,430,000
1945-46	1,750,000	2,375,000	2,400,000	3,950,000
1946-47	1,320,000	1,905,000	2,701,000	4,444,000
1947-48	270,000	670,000	370,000	1,100,000

TABLE 5

Average daily evolution of carbon dioxide in milligrams per 100 gm. of dry soils

Year	Block III a	b	c	Block V a	b	c	Block VII a	b	c	Block VIII a	b	c
Pre-irrigation 1939-40	4.3	7.4	72.1	6.6	9.8	48.5	7.1	11.0	54.9	11.6	11.2	nil
Post-irrigation												
1940-41	6.3	14.6	123.8	6.4	11.6	81.3	16.5	16.0	nil	6.8	10.9	59.3
1941-42	2.7	6.0	122.2	6.2	7.1	14.5	5.5	9.1	65.5	8.6	12.3	43.0
1942-43	3.9	10.7	174.4	8.8	20.8	136.3	24.0	16.0	nil	25.7	23.3	—
1943-44	2.2	5.7	159.2	4.9	9.6	95.9	8.8	11.9	35.2	9.8	10.5	7.1
1944-45	2.8	7.9	182.2	6.5	15.3	135.4	11.8	17.7	51.2	18.9	17.1	—
1945-46	5.3	15.7	196.2	21.8	28.7	31.6	25.1	26.5	5.6	25.8	34.8	34.9
1946-47	2.9	10.7	271.0	12.8	18.5	44.2	16.7	21.6	28.1	21.7	21.6	—
1947-48	4.3	11.0	156.4	13.2	14.8	27.5	15.9	24.4	53.9	20.2	19.2	—

(a) Soil alone; (b) Soil + 1% dextrose; (c) % increase.

Microbiological population was increased in all the blocks more or less equally during the first year of irrigation. In the second year, however, there was a drop in Block III which was unmanured. Whereas in block VII, cultivated fallow, the population reached the maximum. This fall in block III was due to the absence of easily available organic matter required by the micro-organisms and depletion of the plant food by the crop grown. On the other hand, block VII which was fairly rich in organic matter, as judged by the high production of carbon dioxide in the pre-irrigation samples, coupled with cultivated fallow treatment was more fertile than the rest. Block VIII which was manured and aerated (garden cultivation) was first in rank during the first year and second during the second year. In general, this block topped the list during the experimental period. Block V, though received organic manures, was under wet cultivation. The increase in the microbiological population was not high and remained stationary during the second year. The limiting factor was aeration in this block. There were viscissitudes in the microbial population in all the blocks during the post-irrigation period. Lack of adequate rainfall in 1942-43, was probably responsible for a marked depression in the microbial numbers. They got stabilised in block III and V in the sixth year of irrigation. On the other hand, in block VII and VIII which were richer and well aerated, it took longer time.

Irrigation alone was not sufficient to maintain a high level of microbiological population. The presence of easily available organic matter and good aeration are essential in addition to irrigation to obtain maximum benefit. Adequate and well distributed rainfall is favourable to proper multiplication of micro-organisms.

The microbiological activity followed more or less the same trend as their population. The maximum values were, however, reached in the sixth year of irrigation.

The addition of dextrose, an easily available energy material, increased the microbial activity to the maximum extent in block III, followed by blocks, V, VII, and lastly VIII, and was in an inverse ratio to the organic matter content of the soils. Block V, though received organic manures, on account of wet cultivation *i.e.* lack of adequate aeration, the organic matter could not be utilised to a marked extent for microbial activity. When dextrose was added and aerated, appreciable increase could be observed.

Fallowing also favoured microbial population and activity as it enhanced soil fertility. The plant nutrients were retained in the soil and the passing of blade harrow provided necessary aeration. This accounts for the superiority of block VII to blocks III and V.

Table III shows that total salt content of the surface foot of the soil decreased during post-irrigation period. The injurious salts could not rise to the top to impair microbial multiplication and activity.

SUMMARY

Nine years' study of the microbiological changes brought about when rainfed, black soils of Rayalseema (Siruguppa) were converted into irrigated lands reveals that the microbiological population increased considerably during the first year of irrigation. It was followed by a fall in the subsequent years and got stabilised. Maximum values were observed, in general, in block VIII which was under garden land cultivation.

The microbial activity was influenced mainly by the supply of available organic matter. Here also, Block VIII was the best of all the treatments. The essential factors for maintaining high microbial population and activity are (1) irrigation ; (2) available organic matter; and (3) aeration.

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Nutrient Status of Some West Bengal Soils as Determined by Rapid Chemical Methods

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Within the last couple of decades or so rapid methods for assessing nutritional status of soils and diagnosing crop failure have been introduced by Anderson and Noble (1937), Baver and Bruner (1939), Bray (1940), Carolus (1938), Morgan (1941), Peech and English (1944) and others. The importance of these methods is now appreciated by practical workers and has also been emphasised by several workers in this country.

Recent tendency to interpret soil fertility is based primarily on the exchangeable category of ions. The usefulness or otherwise of any mechanism rests finally on the extent of correlation of the chemical tests on a wide variety of soils with the yield data of crops. With this object in view, a series of studies has been envisaged. The present paper of this series reports the preliminary observations with a number of paddy growing soils of Burdwan and Hooghly districts of West Bengal. The selected lands may be distinguished on the basis of level, the low lying lands being put to *aman*, and the high lying ones to *aus* paddy. The overall effect of the level of the lands is likely to be reflected in their nutrient contents.

EXPERIMENTAL

The soil samples were collected from 0″—6″, 0″—8″ or 0″—9″ depths of the *aman* and *aus* paddy lands of 16 villages from Burdwan (B) and 17 from Hooghly (H) districts.

The nutrient status of the soils was determined by analysing the soil extracts obtained by treating the soil with a 4.8 pH NaOAc—HOAc buffer solution according to the procedure described by Peech and English (1944). It consisted in shaking for half an hour a mixture of 10 gm. of 100 mesh air dry soil and 50 cc. of the buffer solution and filtering through Whatman No. 32 or 42 filter paper. The extracts were clear and colourless and hence the prescribed treatment with activated charcoal was not necessary. The above procedure, it should be pointed out here, is followed in a number of States in the U. S. A. and the manurial schedule is also prescribed on the basis of the results of analysis of the soil extract. The analysis includes the determination of P, K, NH_4, Ca, Mg, Fe, Al, Mn and pH. In view of the fact that small quantities are involved colorimetric methods are more advantageous; they are also quick, and for routine studies dealing with a large number of soil samples, rapid methods, which are sufficiently accurate, are highly desirable.

The methods of producing colour or turbidity (*cf.* Peech and English, *loc. cit.*) are briefly referred to below. The EEL photo-electric colorimeter was used for comparison of colour or turbidity. In every case calibration curve was obtained and its reproducibility was verified and checked occasionally. For accuracy, only the linear portion of the calibration curve was utilised for which the extracts had to be suitably diluted. All the chemicals used were of reagent quality or of analytical grade.

Ammonia-nitrogen: By nesslerisation, the colour being stabilised by gum acacia. (200 lb. p.a.)*

*The figures in brackets show the maximum amount that could be determined on the linear portion of the graphs.

Calcium: turbidimetrically as calcium citrate stabilised by soap solution (1600 lb. p.a.) using green filter.

Aluminium: colour developed with aluminon reagent and stabilised by a starch solution (50 lb. p.a.).

Phosphate: as molybdenum blue, the reduction of the phosphomolybdate being effected by a stannous chloride-oxalic acid mixture, instead of the acidified stannous oxalate solution (13.3 lb. p a.).

Manganese: as permanganate, the oxidation being effected by sodium bismuthate in sulphuric acid solution (200 lb. p.a.).

Iron: colour developed by orthophenanthroline reagent (40 lb. p.a.).

Magnesium: colour developed by titan yellow (84 lb. p.a.).

Potassium: turbidimetrically as cobaltinitrite, stabilised by isopropyl alcohol, using a red filter provided with the colorimeter (200 lb. p.a.).

RESULTS AND DISCUSSIONS

The extracted amounts expressed in lb./acre of nitrogen, potash, phosphate, calcium, magnesium, aluminium, manganese and iron of these samples and their pH values are shown in tables 1 and 1a. Of the various constituents analysed, K, Ca and Mg seem to be appreciable in most of the soils which are, however, more or less poor in phosphate and ammoniacal nitrogen. The ammoniacal nitrogen contents have been determind in view of the fact that many plants, paddy in particular, are now supposed to take up nitrogen in this form from the soil. The NH_4-N is probably present in the soil as exchangeable NH_4 and as such its maximum content and ease of release are largely determined by the base exchange characteristics of the clays present in the soil. This aspect

TABLE 1

Analysis of the extracts of soils from the low-lying lands

(Expressed as lb./acre)

Soil Sample No.	NH_4-N × 10	K × 100	PO_4 × 10	Ca × 1000	Mg × 100	Al × 10	Mn × 100	Fe × 100	pH
1B	4	4	3.5	1.8	3.5	30	1.2	3	5.1
2B	5	2	1	3.6	3.5	12.5	1.7	1.2	5.75
3B	5	6	1	0.8	6.2	15	0.4	3.4	4.0
4B	8	4	2	5	1.6	10.5	2.1	1.1	5.8
5B	5	4	14	5	1.5	7	0.75	0.3	6.7
6B	5	4	1.5	2	6.2	12.5	1.75	2	5.6
7B	4	4	7	2.5	5	10	1.75	2.9	5.1
8B	4	—	—	2.8	7.5	9	2.25	2.8	5.2
9B	4.5	—	—	6.4	10	10	1.75	1.2	5.5
10B	4.5	—	—	3.2	7.5	10	2	4	5.1
1H	4	2.6	—	1.6	7.2	4.5	1.9	0.9	5.9
2H	4	9	—	3.1	8	1.5	1.45	0.12	6.9
3H	4.5	—	—	4	1.2	5.0	1.4	0.2	6.4
4H	5	1.9	—	1.4	6.2	10	1.25	1.7	5.5
5H	4	—	—	1.2	5	12	0.4	1.3	5.3
6H	4.5	6.5	—	2.6	6.2	4	1.85	0.35	6.3
7H	4	23	—	0.8	3.7	4.5	0.5	0.8	6.3

TABLE 1a

Analysis of extracts of soils from the high-lying lands

Expressed as lb./acre

Soil Sample No.	NH_4-N × 10	K × 100	PO_4 × 10	Ca × 1000	Mg × 100	Al × 10	Mn × 100	Fe × 100	pH
11B	4.5	5	2	1	2.35	11	0.8	1	5.15
12B	5	6	3.5	2	4.5	3.5	1.9	0.4	6.1
13B	3.5	4	16	6	4.5	6	0.4	0.2	6.3
14B	3.5	3	13	6	12	3	1	0.2	6.9
15B	2	5.5	2	1.6	5	3.5	1.8	1.25	5.9
16B	1.5	5.75	2	1.2	4.5	2.5	1.1	0.3	5.9
8H	1.5	4.5	2	2.4	12	4.5	1.5	0.4	6.3
9H	12.5	2.73	3	1.2	2.25	4	1.75	0.92	5.8
10H	5	4.5	3.5	2.4	2.25	4	3	0.52	5.8
11H	3	4.5	6	2	2.25	3.5	2.75	0.65	6.0
12H	4	2.65	6	2	2	10	2	1.4	5.2
13H	4	2.65	12.5	5.2	4	5	1.45	0.42	7.25
14H	4	1.50	7	2.8	2.25	4	3.25	0.6	6.2
15H	4.5	2.65	5	4	2.25	10	4	1.7	6.65
16H	1.6	1.5	6.5	1.6	2.1	4	1.05	1.25	5.5
17H	2	4.5	10	2	2.25	2.8	3.26	0.46	5.7

TABLE 2

Statistical analysis—'t' test

Nutrient	s	s^2	t	d. f.	't' at .05	't' at .01
NH4-N	1.16	0.41	3.58*	31	2.04	2.75
K	1.75	0.69	0.28	25	2.06	2.79
PO_4	0.21	0.10	14.9 *	16	2.12	2.92
Ca	1.63	0.57	0.18	31	2.04	2.75
Mg	3.49	1.21	2.83*	31	,,	,,
Al	0.24	0.085	56.3 *	31	,,	,,
Mn	0.70	0.24	2.10*	31	,,	,,
Fe	0.86	0.30	2.90*	31	,,	,,

requires further investigation. The presence of Al and Fe in an exchangeable form is fairly characteristic of acidic soils, and these ions are supposed to be toxic, if present in large quantities. The pH values of the soil samples are on the acid side lying mostly between 5 and 6.5. The contents of Al and Fe are generally higher in the acid soils. The manganese content is, on an average, higher than Al but lower than Fe.

The soil samples used in this investigation may be differentiated on the basis of the level of the lands from which they have been collected. The low lying lands, from which 16 samples have been collected, grow *aman* paddy as the main crop, whereas the high lying lands from which the remaining 17 samples have been obtained are meant for *aus* paddy or perhaps also jute. In order to see if the soils really differ, as the data apparently show, in their nutrient status, the data were subjected to the 't' test by statistical methods. The results of this analysis are given in table 2.

It will be seen that the two categories of soils show several points of difference on this basis. Thus, the content of NH_4-N is higher (at 1% level) in the case of *aman* paddy than in the *aus* paddy lands. Similar is the state of affairs with Mg, Al and Fe. The contents of PO_4 (1% level) and Mn (at 5% level) are, on the other hand, higher in the high lying *aus* lands than in the *aman* paddy lands. The contents of calcium and potassium do not appear to be significantly different for the two categories of soil.

SUMMARY

The surface soil samples from *aman* and *aus* paddy lands of 16 villages of Burdwan and 17 villages of Hooghly districts of West Bengal have been analysed, by rapid chemical methods, for soil reaction and their contents of NH_4-N, P, K, Ca, Mg, Fe, Al and Mn.

Statistical analysis of the results shows that the content NH_4-N is higher in the case of low-lying *aman* paddy lands than in the high-lying *aus* paddy lands. Similar is the state of affairs with Mg, Al and Fe. The contents of P and Mn are higher in the *aus* paddy lands, but those of Ca and K are not significantly different in the two classes of soil.

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Geology of Little Rann of Kutch and its Bets

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In his classic memoir on the geology of Kutch, Wynne (1892) divided the Jurassic rocks of Kutch into four main divisions, Patcham, Chari, Katrol and Umia in order of their antiquity. The sedimentary sequence in Kutch ranges from middle Jurassic to late Tertiary with a major gap between the Cretaceous sediments and the Tertiary volcanics. The general succession of the strata can be summed up as follows.

Sub-recent and Recent Alluvium		
Stratified traps (with intertrappean beds)		U. Cretaceous
Infra-trappean Grits		
Bhuj Series	...	M. Cretaceous
Upper Umia	...	L. Cretaceous
Lower Umia		
Katrol Series	...	U. Jurassic
Chari ,,		
Patcham ,,	...	M. Jurassic
Metamorphics	...	Cambrian

Rajnath (1933) carried out intensive field mapping and, on the basis of palaeontological as well as field observations, discovered six distinct unconformities in the Jurassic sequence of Kutch. He showed thereby that, during the deposition of Jurassic sediments, the sea level as not constant but oscillated much. Satyanarayana (1951, 1954) and Sen and Satyanarayana (1953) reported some preliminary observations on the soils and their mineralogical composition. In the present paper, attention is especially drawn to the geology of the islands or Bets' in the Little Rann of Kutch, which has not been recorded before.

PHYSIOGRAPHY OF LITTLE RANN

Little Rann, for the most part, presents a vast, nearly contiguous flat plain of black alluvial soil. The surface is much cracked up in summer and is interrupted here and there by superficial patches of salt encrustations, which at places stretch for considerable distances. The monotony of an otherwise flat Rann surface is, however, relieved by the presence of a number of islands, which rise from a few feet to about a hundred feet above the average flood level of the Rann. Generally the high contoured bets (Group 1) expose good sections of the rock strata while the low contoured ones (Group 2) are singularly bare of any good rock outcrops. The bets coming under the latter group are, however, capped by rich alluvium, which permits thick, luxuriant vegetation. Only one bet is inhabited (Nanda) and here the richness of the alluvium is rightly made use of in promoting some amount of cultivation. The most important bets are listed in groups 1 and 2.

GROUP 1. *(Elevation 20 to 150 ft. approximately)*

(a) Mardak Bet (23° 22′ 30″ to 23° 23′ ; 71° 3′ to 71° 7′ 30″)
(b) Keshmari Bet (23° 16′ to 23° 17′ ; 71° 0′ 30″ to 71° 2′)
(c) Bhangarwa Bet (23° 16′ to 23° 17′ ; 71° 6′ 30″ to 71° 7′ 30″)
(d) Dhutarimata (23° 30′ to 23° 33′ ; 71° 19′ to 71° 21′ 30″)

GROUP 2. *(Elevation less than 20 ft.)*

(e) Pung Bet (23° 23′ to 23° 30′ ; 71° 8′ 30″ to 71° 8′ 50″)
(f) Shedwa Bet (23° 29′ 50″ to 23° 30′ ; 71° 8′ 30″ to 71° 8′ 50″)
(g) Nanda Bet (23° 34′ 50″ ; 71° 8′ 50″)
(h) Wasra Solanki (23° 23′ to 23° 25′ ; 71° 22′ 30″ to 71° 27′)

GEOLOGICAL SEQUENCE IN THE BETS

The stratified horizons exposed in some of the above mentioned bets belong to the Bhuj Series, associated with a few outliers of the later traps, coarse gritty sand stones and recent alluvium. The succession of strata is as follows :—

Black alluvium	...	Recent
Coarse gritty sand-stones		Sub-recent
Intrusive traps	...	U. Cretaceous
Bhuj series	...	M. Cretaceous

DETAILED DESCRIPTIONS

Bhuj Series : These are the main series that are exposed in the area and constitute the main rock types in Keshmari, Bhangarwa and part of Mardak Bets. The former two islands are aligned in a line stretching from west to east and consist of low ridges. Bhuj series in these islands start with a basal bed of cream coloured, variegated concretionary clayey sand stones. The concretions are rounded and rod shaped and are made up of essentially brownish red iron oxide. At some places, the bed is traversed by several parallel bands of iron oxide.

These are succeeded by purple coloured ferruginous sand stones, the top layers of which appear more slaggy and comparatively well-laminated than the bottom layers. The sand stones are much weathered and lateritic at places, and exhibit a peculiar concentric weathering on the surface. As Wynne (1892) remarked, the more slaggy and lateritic portions of the bed, resemble the waste heaps of an iron foundry.

The beds have a uniform strike of ENE-WSW, with a gentle dip of 3 to 4° towards NNW. No fossils have been found despite close search.

Traps : The trappean basalts come next in succession since the infratrappean grits exposed elsewhere in Kutch (East of Bachau) are missing in the bets.

They outcrop on the southern slopes of the Mardak Bet. The bet, highest in the Little Rann, stretches east west longitudinally almost in the same line as the outstretched tongue of the mainland at Gon. The outcrops are exposed as four distinct and apparently disconnected patches at the base of the southern flanks of the bet along a line, stretching from west to east approximately parallel to the configuration of the bet. The intervening areas consist either of purple ferruginous sand stones of Bhuj series or more usually black alluvium.

As elsewhere, the traps here also occupy the low lying valleys while the higher reaches of the bet are occupied by coarse gritty sand-stones.

In the hand specimen, the trap shows a dark greenish color, fine grained texture and is very compact. It breaks with a conchoidal fracture.

Thin section of the rock reveals a considerable amount of interstitial glass and abundant plagio-clase and augite with smaller amounts of iron oxides chiefly magnetite.

The surface rocks are much disintegrated and are traversed by numerous rhombic joints. The entire bed thus shows a sort of rhombic splintery weathering. Because of their distinct contacts with the surrounding rocks, their restricted distribution in roughly elongated patches and their occurrence as apparently disconnected patches intervened by purple sand stones, the traps might be considered intrusive into the latter. Wynne (1892) considered similar occurrences on the mainland to have formed the initial feeders, for the later effusive traps.

Sub-recent sand-stones : The traps are succeeded on the upper reaches of the Mardak Bet by pale yellow, coarse, loosely cemented laminated sandstones. In the immediate vicinity of the traps, *i. e.* on the southern slopes of the bet, they show a NE-SW trend with a some what high dip of 20° towards N. W. The strike changes abruptly to East-West on the top of the hill with a gentle dip of 4° to the South. The general alignment of the beds, however, seems to coincide with those observed near Kanmer and Gon in the main land.

Exposures of similar sand-stones are also found on the Shedwa Bet. They have the same N.E.-S.W. trend with a gentle north-westerly dip, but here the rocks are more flaky and contain considerable amounts of mica. Embedded in the sand stones are scanty, ill developed patches of nodular concretions of lime which have a highly deceptive altered granitic appearance.

Recent alluvium : The mainland to the east of Little Rann is wholly made up of recent alluvium, brought down every year by the flood waters of the three main rivers, Banas, Saraswati and Rupen and numerous other streamlets. The Little Rann itself, which was a shallow arm of the sea in the not very distant past, was gradually silted up to the present level by the enormous amounts of sediments brought down by the north as well as the west flowing rivers principally. It is to be recognized that the Little Rann and surrounding areas are covered by two types of alluvium, the black and cream coloured. The former, of course, is the master alluvium that constitutes the entire Little Rann but the latter is however met with in most of the bets as a thin cover, over the rocks. The gullies, depressions and slopes of the bets are again capped by black alluvium, obviously transported and deposited by strong winds that are so common in the Little Rann.

The Black alluvium that constitutes the Rann surface is similar to the '*Regur*' or the black cotton soil, that is so predominant in the Deccan Plateau, and is generally well stocked in the elements, necessary for plant growth. But the high percentage of salt in the soil has temporarily made it unfit for the growth of vegetation. When once the salts are drained out, the soil becomes useful for cultivation. The phenomenon is well illustrated by the small mounds in some places, hardly rising to about six inches above the Rann surface, supporting good amount of grass vegetation and they contain lesser amounts of salts in comparison with the rest of the surrounding area.

On the basis of heavy mineral analyses of a number of profiles, Sen and Satyanarayana (1953) have concluded that the Rann sediments had a common environment of sedimentation throughout. They inferred further that the traps are the dominant parent materials that contributed sediments in the south, while the sediments to the north showed

increasing admixture of non-basaltic materials derived possibly from the Metamorphics of Rajasthan and Kutch.

Salt and Gypsum: Because of the encroachment of the sea in the high tide period every year, the soils of Little Rann possess a high persentage of salts detrimental to plant growth. The patches of white salt encrustation on the surface, at times, stretch for considerable distances. The salt content in the soil, however, does not seem to be uniform throughout. The presence of salt pans all along the southern and eastern borders, point to a higher salt content in these areas than in the northern and western margins.

The gypsum deposits of the Little Rann are negligible. Gypsum occurs as small yellow transparent blades and needles in the bluish clay horizon 2 to 3 ft. below the surface. The crystals are generally tabular and are usually 2 in. to 4 in. in length. The total gypsum available is however not known.

SUMMARY

The geology of the Little Rann and its bets is studied. Little Rann is made up of black alluvium chiefly with patches of white salt encrustations deposited during the high tide invasion of the sea from S. W. The chief rock formations exposed in some of the bets belong successively to the Bhuj series, Deccan trappean Basalts, Sub-recent sand-stones and Recent alluvium.

The Sub-recent sand-stones in Mardak bet show evidences of much disturbances indicated by their contrasted dips within a small area. The general alignment of the bet as well as the strata are, however, in agreement with those observed near Kanmer and Gon on the main land. As such these beds may be considered as the continuation of the same anticlinal axis, a conclusion guessed by Wynne (1892). Possibly this is also the same anticline referred as the Habo anticline by Auden (1951).

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Influence of the Method of Storage on the Microbiological Properties of Soil Samples

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For purpose of microbiological analysis, a fresh sample of soil is likely to give the best results, but this procedure is often not possible of adoption, especially in cases where the soil fields are situated far away from the analytical laboratory or where a large number of samples have to be taken simultaneously and analysed later. In such cases, it is the practice to air-dry the samples and preserve them for microbiological analysis for some period, which in some cases may extend over some weeks or even months. The method of storage of soil samples varies greatly in different laboratories, ranging from storage in cloth bags or paper cartons to storage in sample bottles with glass or rubber stoppers. The object of the present investigation was to examine whether the adoption of different methods of storage produces differences in the microbiological properties of the soil e.g. its ammonifying, nitrifying and nitrogen fixing powers. Reviews of work relating to the ammonifying, nitrifying and nitrogen fixing powers of soil and associated microbiological and biochemical aspects have been given by a number of workers (Waksman, 1932, 1952; Quastel, 1947; Quastel and Scholefield, 1951; Wilson and Burris, 1947; Wilson, 1952; Acharya and Jha, 1954; Acharya and Jain, 1954; Russell, 1950). Not much work, however, appears to have been done on the special aspect now under consideration, *viz.* the differences that occur in the microbiological properties of the soil due to adoption of different methods of storage.

EXPERIMENTAL

Five different soils were used in the present investigation and two methods of storage were compared, *viz.* (a) storage in glass bottles whose mouths were plugged with cotton wool or with cloth fixed by rubber bands; by these means free aeration of soils in bottles was ensured and the method has hereafter been called the "aerobic" method of storage; and (b) storage in glass bottles whose mouths were closed by rubber or glass stoppers, which method will herein be referred to as the "anaerobic" method of storage. Storage periods of 6 and 12 months were examined. At the end of each period, samples of soil were taken out from both the "aerobically" and "anaerobically" stored bottles and compared for their ammonifying, nitrifying and nitrogen fixing capacities. In the case of method (b), the soil aliquots were weighed out as quickly as possible after opening the bottles and added to the different media. In view of the long period of anaerobic storage, *viz.* 6 and 12 months, it is believed that the error caused by the short period of aerobiosis during weighing the samples would have been of a low order, especially as the media used for comparing microbial activity were incubated aerobically in all cases.

The ammonifying power of the soil was tested by adding one gram portion of the soil to 100 ml. of Remy's peptone medium and determining the amount of ammonia formed after incubation for 24 hours at 35°C. In view of the fact that ammonia producing enzymes like urease have been shown to be active in soil (Conrad, 1942), the values obtained for ammonifying power would measure the activity of both the microbial and enzymatic agencies present in the soil capable of producing ammonia from peptone medium.

The nitrifying power was determined by adding one gram portion of the soil to Omeliansky and Winogradsky's media No. 1 and 2 and estimating the nitrite formed in the

first case by the Griess Ilosway method and the nitrate formed in the second case by the phenol-disulphonic acid method. The rate of nitrifiability of soil nitrogen was also determined by using the soil itself as the medium, by incubating 300 g. portions of the different soils in bottles under optimum conditions of moisture (40% of the water holding capacity), temperature (30°C) and aeration (by periodic stirring of the mass).

The nitrogen fixing capacity of the soil was determined by estimating the amount of nitrogen fixed in Ashby's mannite medium; one gram of soil was added to 100 ml. of mannite medium and incubated for 7 days at 30°C before estimating the nitrogen fixed.

Fuller details of the methods adopted are given in a previous paper (Acharya, and Jha, 1954· *vide* also Acharya and Jain, 1954). The results obtained are presented in Tables 1 to 5.

1. *Ammonifying Power*: Table 1 shows the values for ammonifying power obtained with the soil samples after storage under aerobic and anaerobic conditions for 6 to 12 months.

TABLE 1

Ammonifying power of differently stored soils

Soil	Mg. of NH_3 formed in 24 hours at 35°C from 100 ml. of Remy's solution.			
	By soil after 6 months of		By soil after 12 months of	
	aerobic storage	anaerobic stroage	aerobic storage	anaerobic storage
1. Delhi soil (I. A. R. I. Phipp's Lab—sandy loam)	14.45	13.51	13.94	10.52
2. Delhi soil (I. A. R. I. Top Block 3A—sandy loam)	16.40	16.40	17.00	16.66
3. Pusa (Bihar) soil—calcareous...	16.15	13.77	15.80	17.00
4. Guntur black cotton soil ...	14.53	15.21	20.22	17.68
5. Coimbatore black soil ...	14.83	15.13	20.56	16.66

Th data presented in table 1 would show that there is, in general, no appreciable difference between the ammonifying powers of soil samples stored for 6 and 12 months under aerobic and anaerobic conditions. This is possibly due to the fact that many soil ammonifyiug organisms are capable of forming spores (Waksman, 1932) and hence are able to resist the adverse effect of prolonged anaerobic storage. It is also possible that the ammonia producing enzymes in the soil (Conrad, 1942) are not adversely affected by anaerobic storage.

II. *Nitrogen fixing power* : Table 2 gives the values for the nitrogen fixing powers of the 5 soil samples stored under aerobic and anaerobic conditions for 6 and 12 months.

A perusal of the data contained in table 2 would show that soil samples stored under anaerobic conditions for 6 months show in general slightly higher nitrogen fixing powers than the aerobically stored samples, but after 12 months storage, the anaerobically stored samples show somewhat lower nitrogen fixing powers than the aerobically stored samples. In both the cases, the differences are not appreciable and it may be taken that there is no appreciable difference between the effects of the two methods of storage on the nitrogen fixing power of the soil.

TABLE 2

Nitrogen fixing powers of differently stored soils

Soil	Mg. of N fixed per 100 ml. of Ashby's mannite medium in 7 days at 30°C			
	By soil after 6 months of		By soil after 12 months of	
	aerobic storage	anaerobic storage	aerobic storage	anaerobic storage
1. Delhi soil (I. A. R. I. Phipp's Lab—sandy loam) ...	7.49	9.06	7.77	5.67
2. Delhi soil (I. A. R. I. Top Block 3A—sandy loam) ...	10.78	11.62	9.84	9.42
3. Pusa (Bihar) soil—calcareous...	9.52	9.48	8.81	8.60
4. Guntur black cotton soil ...	9.31	10.92	8.00	7.12
5. Coimbatore black soil ...	10.08	8.75	8.84	5.97

III. *Nitrifying power*: Table 3 gives a comparison of the nitrite forming capacity of the differently stored soils, using Omeliansky's ammonium sulphate medium. Table 4 gives the values for nitrate formed by the above soils, using Winogradsky's nitrite medium.

A comparison of the data contained in tables 3 and 4 against the data contained in tables 1 and 2 would show that, as compared to the ammonifying and nitrogen fixing powers, the nitrifying power of the soil is much more sensitive to anaerobic conditions. After 6 months of storage in rubber or glass stoppered bottles, the nitrifying power, as measured by the formation of nitrite from ammonium salt, is reduced by 50 to 70 per cent, though there is much variation from soil to soil. At the end of 12 months storage, nitrifying powers of some of the samples under anaerobic storage decreased to a level of about 10 to 20% of that of the aerobically stored samples.

TABLE 3

Nitrifying powers of differently stored soils

(Omeliansky's No. 1 medium)

Soil	Mg. of NO_2-N formed per 100 ml. medium in 1 week at 30°C.			
	By soil after 6 months of		By soil after 12 months of	
	aerobic storage	anaerobic storage	aerobic storage	anaerobic storage
1. Delhi soil (I. A. R. I. Phipp's Lab—sandy loam) ...	0.80	0.38	0.66	0.09
2. Delhi soil (I. A. R. I. Top Block 3A—sandy loam) ...	1.11	1.00	1.30	1.00
3. Pusa (Bihar) soil—calcareous...	2.00	1.14	1.72	1.05
4. Guntur black cotton soil ...	1.02	0.33	1.32	0.17
5. Coimbatore black soil ...	1.08	0.69	0.88	0.15

TABLE 4

Nitrifying powers of differently stored soils

Winogradsky's Medium No. 2 (Nitrite)

Soil	Mg. of NO_3-N formed per 100 ml. medium in 2 weeks at 30°C			
	By soil after 6 months of		By soil after 12 months of	
	aerobic storage	anaerobic storage	aerobic storage	anaerobic storage
1. Delhi soil (I. A. R. I. Phipp's Lab—sandy loam) ...	0.546	0.484	0.750	0.100
2. Delhi soil (I. A. R.I. Top Block 3A—sandy loam) ...	0.781	0.641	0.710	0.500
3. Pusa (Bihar) soil—calcareous...	2.040	0.625	1.620	0.700
4. Guntur black cotton soil ...	1.062	0.406	1.160	0.250
5. Coimbatore black soil ...	1.180	0.515	1.040	0.200

As regards the oxidation of nitrite to nitrate in Winogradsky's medium No. 2 (*vide* Table 4), the position is similar to the oxidation of ammonia to nitrite, as reported in table 3. The organisms connected with this reaction appear to be highly sensitive to anaerobic conditions, and there is considerable fall of nitrifying power in samples stored anaerobically for 6 and 12 months, as compared to aerobically stored samples.

IV. *Nitrifiability of soil nitrogen* : Table 5 gives the data obtained for the nitrifiability of soil nitrogen in soil samples stored under aerobic and anaerobic conditions.

TABLE 5

Nitrifiability of soil nitrogen in differently stored samples

Soil	Mg. of NO_3-N formed per 100 gm. soil			
	In 1 month	In 2 months	In 3 months	In 4 months
1. Delhi soil (I. A. R. I. Phipp's Lab.—sandy loam).				
After aerobic storage for 9 months.	1.04	1.125	1.125	1.50
After anaerobic storage for 9 months ...	1.50	1.66	1.50	1.50
2. Delhi soil (I. A. R. I. Top Block 3A—sandy loam)				
After aerobic storage for 9 months ...	1.25	1.25	1.58	1.75
After anaerobic storage for 9 months ...	2.00	2.38	3.00	3.00
3. Pusa (Bihar) soil, calcareous				
After aerobic storage for 9 months ...	1.50	1.78	2.50	3.00
After anaerobic storage for 9 months ...	1.50	1.78	3.13	3.50
4. Guntur black cotton soil				
After aerobic storage for 9 months ...	1.04	1.32	1.32	1.58
After anaerobic storage for 9 months ...	2.04	3.33	4.10	4.10
5. Coimbatore black soil				
After aerobic storage for 9 months ...	1.25	1.30	1.30	1.58
After anaerobic storage for 9 months ...	1.66	2.50	3.00	3.75

The nitrifying power as determined by the nitrifiability of soil nitrogen shows a different picture from the nitrifying power as determined in Omeliansky and Winogradsky's media. In the case of the soil medium, there appears to be no adverse effect exerted by anaerobic storage for 9 months. On the other hand, anaerobic storage of the soil seems, in general, to have a beneficial effect in increasing the quantity of nitrate formed in the soil in 4 months' time. This may possibly be due to the fact that the anaerobic ammonifying organisms have been stimulated by anaerobic storage and hence the quantity of ammonia formed from the soil by the ammonifiers and subsequently converted into nitrate by the nitrifying organisms is greater. It is also possible that, as in the case of partial sterilization, of soil (Russell, 1950), which increases the subsequent formation of ammonia and nitrate, the organisms which are harmful for ammonifying and nitrifying processes may be partially destroyed during the period of anaerobic storage and thus the subsequent formation of ammonia and nitrate may be accelerated. The matter requires further examination, especially as in some cases, e.g. the black soils from Guntur and Coimbatore, the beneficial effect of anaerobic storage on the subsequent nitrification of the soil organic matter is very marked.

SUMMARY

Storage of soil samples in bottles closed with cotton wool or cloth (aerobic storage) was compared against storage in bottles closed with rubber or glass stoppers (anaerobic storage) in regard to the effect of the treatments on the ammonifying, nitrifying and nitrogen fixing powers of the soil after 6 and 12 months of storage. In respect of ammonifying and nitrogen fixing powers, there was no appreciable difference between the two methods of storage, but the nitrifying power, as determined in Omeliansky and Winogradsky's media was much lower in the anaerobically stored samples, as compared to the aerobically stored samples.

The nitrifiability of soil organic matter, as measured by the quantity of nitrate formed by incubation of the soil under optimum conditions of moisture, temperature and aeration, was higher in the case of soil samples which had been previously kept stored under anaerobic conditions, as compared to soils which had been stored under aerobic conditions.

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Effect of Synthetic Soil Conditioners on Soil Structure

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It is recognised that the productivity of a soil depends on good soil structure besides its nutrient status. The objective of good soil management is to ensure good soil structure. Soils with good structure drain well and can be ploughed and cultivated easily, and offer less resistance to the emergence of seedlings. Correlations have been noted by many workers between different levels of physical conditions of the soil and crop production.

Since long, attempts have been made to improve the structural status of soils by the addition of organic manures. Chemicals, like potassium and sodium silicates (Laws, 1951; Laws and Page, 1946) and some cellulose compounds were tried, but these proved either toxic or less effective. The constituents derived from the decomposition products of the organic matter are the polyuronides and bacterial polysaccharides. Knowledge of these naturally occuring substances that improve soil structure indicated the possibility of developing methods for synthesizing substances having similar properties. Recently in the U. S. A. and other European countries, poly-electrolyte resins have been produced under various trade names. These products are familiarly known as 'Soil Conditioners.'

The discovery of synthetic soil conditioners has been received with great interest all over the world and a series of papers have been published by the personnel of the Monsanto Chemical Company, the manufacturer of 'Krilium' Soil Conditioner (Hedrick and Mowry, 1952; Ruehrwein and Ward, 1952 and Weeks and Colter, 1952). Soil conditioners were put to laboratory and field tests which showed that their application at the rate of 0.01 to 0.1 per cent to soil having poor structure increased the aggregation as determined by wet sieving (Hedrick and Mowry, 1952). The increased stability of soil aggregates due to soil conditioners on different soils has been reported by many workers: Taylor and Martin (1953) on fine-textured Miami silt-loam and other soils; Martin (1953) on several Ohio soils; Hagin and Bodman (1954) on some California and Israeli soils; Kapoor and Nair (1954) on black clayey soil and red loams; Emerson (1954) on acid and calcareous soils at Rothamsted; Moss *et al.* (1954) on some soils of New Zealand; Hill (1954) on some Canadian soils; Alderfer (1954) on some Pennsylvania soils; Bolton, Fulton and Aylesworth (1955) on Brookstone Clay soil; Allison (1952) on saline and alkali soils; Martin and Jones (1954) on prepared soils containing high percentages of sodium or potassium; Berryman (1953) on a degraded soil; and Hayes and Simpson (1953) on a heavy clay soil of Midlothian (England) have found increase in water stable aggregates with the addition of krilium.

Krilium has also been studied as to its effect on erosion control. Application of ½ lb. of conditioner per 100 sq. feet has, in most cases, provided satisfactory protection to the soil (Weeks and Colter, 1952). About 1 lb. of krilium or less per 100 sq. feet reduced run off (Slater, 1953) and its use may be expected to develop in treating slopes to protect them temporarily against erosion until vegetation is established (Swanson, 1952). Soil conditioners applied to the surface or mixed with the soil generally increased the erodibility by wind but the erosion by water was reduced (Chepil, 1954).

One of the most promising effects of the synthetic soil conditioners is their ability to reduce surface crusting of soils (Pearson and Jamison, 1953). Surface crusting is an

important factor in seedling emergence and in trials on some soils of New Zealand, krilium increased the germination (Moss *et al.* 1954). Field and laboratory tests reported by Jamison (1954) show that the method of soil treatment with a soil conditioner and weather conditions after treatment will modify the effect upon soil crusts formed. When sprayed on the surface, they may give rise to tough soil-plastic crusts that are harder than natural crusts upon drying.

As a consequence of greater aggregation, increases in porosity, water infiltration, and permeability have been obtained (Martin, 1953). The results of a number of experiments have demonstrated that infiltration is increased by the use of conditioners on soils that tend to crust (Pearson and Jamison, 1953). Tests made on alkali soils, that were low in permeability, gave marked increases in permeability with krilium treatment (Allison, 1952).

Hedrick and Mowry (1952) have found that the moisture equivalent of the soil is increased. According to Pearson and Jamison (1953), the soil conditioners cannot cause an important increase in the available water holding capacity.

The effect of soil conditioners on saline and alkali soils has been studied in considerable detail by Allison (1952) who found that they were quite effective in producing water stable aggregates and in increasing water infiltration and permeability. Martin and Jones (1954) also found increased aggregation in conditioner treated dispersed soils containing high exchangeable sodium.

The effectiveness of soil conditioner depends on a number of factors such as soil texture, soil moisture, initial soil structure and the method of application. Sherwood and Engibous (1953) have found that, in general, soils of a high clay contents which compact and crust badly, have responded best to soil conditioners. However, some degree of structural response has been obtained on all soils regardless of initial structure level. Hedrick and Mowry (1952) have found that greater aggregation is obtained on fine textured rather than coarse textured soils. Krilium has been found suitable only for soils with a high clay contents, sand and loamy soils have shown no response (Moss *et al.* 1954). It took more conditioner to effect the same degree of aggregation on the larger sized fractions of silica sand (Martin, 1953). Since the stablizing effect of krilium is related with clay, it may be expected that with low amounts of clay, the effectiveness of krilium will be proportionately less. But Alderfer (1954) has found that in the presence of only a modest amount of silt and clay, considerable quantities of the finer sands may be combined into aggregates larger than 0.25 mm. Laws (1954), while working with Texas soils, found that the conditioner was more effective as an aggregating agent on a sandy loam and clay loam soils than on heavy clay soils. Like soils high in fertility which require no fertilization for maximum crop yields, soil in good tilth will require no krilium for soil structure improvement (Swanson, 1952). Mukherjee (1954) found the absorpsion of krilium by montmorillonite clays to a large extent, the product being more hydrophillic than the original clay.

With soil moisture near field capacity, changes in structural conditions are noticeable within an hour after incorporation (Taylor and Martin, 1953). If too wet, "gumming up" occurs and good mixing is difficult; if too dry, the soil should be mixed after irrigation or rain (Martin, 1953). Krilium in its original form (hydrolysed polymer of acrylonitrile) proved somewhat difficult to incorporate in moist British soils.

The method of application is extremely important. Thorough mixing of the soil aggregating chemicals with the soil is essential for maximum aggregation. The soil conditioners cannot be added to the soil without disturbing it. If not worked in, the conditioners act only on the top eighth of an inch or so of soil. Like nitrogenous fertilizers they do not work down into the soil as the season progresses (Swanson, 1953).

The synthetic soil conditioners are said to be resistant to microbial decomposition (Hedrick and Mowry, 1952). Martin (1953) found that the percentage aggregation decreased substantially with time, but the treated soils were neverthless considerably better aggregated at the end of the second season than were the controls. Mortensen and Martin (1954), by following radioactive tracer technique using C_{14} labeled polymers, found that the syhthetic soil conditioners are resistant to extensive microbial decomposition. Even though the structure stabilized by synthetic conditioners is resistant to microbial attack, the stability can be destroyed by overworking or faulty cultivation (Moss *et al.* 1954).

EXPERIMENTAL

In the present study, three types of soil conditioners namely, Krilium, formulation No. 9, Aerotil and Poly-ack were tested on four different soils ranging from heavy clay soil to a sandy loam.

Krilium formulation No. 9 is a slightly yellowish powder which is highly hygroscopic. Chemically this material is a sodium or calcium salt of a hydrolysed polymer of acrylonitrile. Aerotil is the trade mark used on the soil conditioner produced by American Cyanamid Company. This material is also hydrolysed polymer of acrylonitrile. Poly-ack, is also a hydrolysed polyacrylonitrile, obtained from Wilson Export and Import corporation, New York. This product is a resinous liquid and can only be used with a sprayer. The three materials differ probably in the degree of polymerization. The polyanions of these soil conditioners, with numerous negative charges on them, link up with cations of sodium, calcium and magnesium present on clay particles and these are bound into larger aggregates by polymer bridges (Ruehrwein & Ward, 1952) because the long chain like molecules are much bigger than a clay particle.

The methods followed to evaluate structure in the present study include determination of waterholding capacity, rate of water infiltration or percolation, the state of aggregation and the size distribution and the stability of the aggregates, and the dispersion and sedimentation rates of treated and untreated soils in water. Soil conditioners were applied to soils passing through 2 mm. sieve with moisture at their one-third water holding capacity and mixed thoroughly. After 24 hours, the soils were irrigated to bring the moisture level to their water holding capacity. Then the soils were kept in the sun to bring down the moisture to one-third water holding capacity at which the soil samples were taken, dried and subjected to aggregate analysis by wet sieving (Yoder, 1936).

RESULTS AND DISCUSSION

A desirable soil structure should be as stable as possible. A soil structure can break up in many ways, one of them being that the cementing agents may fail to hold the soil particles together when wet. Therefore, to see the stability of the soil structure, water stable aggregates were determined in treated and untreated soils with different clay contents. A heavy clay soil containing 54 per cent clay was treated with krilium at the rate of 0.05 and 0.1 g. per 100 g. of soil. The results of different sized water stable aggregates, as determined by wet sieving (Yoder, 1936), presented in table 1, indicate that increasing quantities of krilium increased the shift to larger aggregate sizes with corresponding decrease in the smaller sizes. It appears that most of the aggregation has taken place in the size group of 2 mm. to 1 mm.

TABLE 1

Size distribution of aggregates in soil of 54% clay (black soil)

Treatment	Size of the water stable aggregates	Percentage of aggregates on oven dry basis
1. Untreated	Above 2 mm.	nil
	2 mm. to 1 mm.	12.90
	1 mm. to 0.2 mm.	56.40
	below 0.2 mm.	30.70
2. Krilium treated (0.05%)	above 2 mm.	0.30
	2 mm. to 1 mm.	26.00
	1 mm. to 0.2 mm.	52.20
	below 0.2 mm.	21.50
3. Krilium treated (0.1%)	above 2 mm.	2.10
	2 mm. to 1 mm.	37.30
	1 mm. to 0.2 mm.	36.80
	below 0.2 mm.	23.80

TABLE 2

Size distribution of aggregates in soil of 45% clay (black soil)

Treatment	Percentage of water stable aggregates			
	above 1.5 mm.	1.5 to 0.5 mm.	0.5 to 0.15 mm.	below 0.15 mm.
1. Untreated	0.2	3.0	54.4	42.4
2. Krilium treated (0.1%)	9.4	14.1	47.8	28.7
3. Poly-ack (0.1%)	8.3	13.0	47.0	31.7
4. Aerotil (0.1%)	8.0	11.0	46.1	34.9

TABLE 3

Size distribution of water stable aggregates

Soil type	Treatment	Water stable aggregates per cent			
		above 1.5 mm.	1.5 to 0.5 mm.	0.5 to 0.25 mm.	below 0.25 mm.
Black soil (31% clay)	Untreated	—	3.0	68.5	28.4
	Krilium (0.1%)	3.1	10.3	80.8	5.7
Sandy loam	Untreated	nil	nil	16.3	83.7
	Krilium (0.15%)	14.4	15.0	23.0	46.8
	Aerotil (0.15%)	2.5	11.9	34.0	51.6

From the results given in tables 2 and 3, it is seen that by the addition of soil conditioners larger water stable aggregates are produced. Out of three soil conditioners (Table 2) tried, krilium seems to be more effective. In case of black soil, particles below 0.25 mm. size which constitute 28.46 per cent of the untreated soil were reduced to 5.72 per cent. Although aggregate formation is mainly brought about through the agency of clay particles, the addition of increased amounts of soil conditioners (0.15%) has enabled the clay particles to form a network around silt and sand particles to form larger water stable aggregates in a sandy loam. The results given in table 3 show that, with the addition of krilium and aerotil, the aggregation percentage above 0.25 mm. size is increased from 16.3 in untreated soil to 53.2 per cent and 48.4 per cent respectively. To be effective in creating favourable structural conditions, it is commonly assumed that these aggregates should have diameters greater than 0.25 mm. (Alderfer, 1954).

The effect of soil conditioners to form and to stabilize soil aggregates against the slaking action of water can be of great use on soils with poor structure, in which the crumbs break down by rainfall or irrigation water to form smooth, crusty surface which may impair normal plant growth. In the opinion of Michaels and Lambe (1953), it appears likely that polyelectrolytes flocculate the fine soil particles into stable, water resistant aggregates, and stabilize such aggregates as may exist prior to addition of polyelectolyte.

To determine the elementary units of stable aggregates in a heavy clay soil with 54% clay, treated and untreated soils were dispersed in water. Suspensions were pipetted out at 10 cm. depth for unaggregated silt and clay. The results are presented in table 4. Similarly, another soil with 31 per cent clay was dispersed in water with and without the addition of krilium. In this case, the suspensions were pipetted out at 10 cm. depth after fixed intervals. In another experiment, a sandy loam was kneaded till it lost its original structure. The soil thus prepared was dispersed in water with and without krilium to determine the effect of unaggregated silt and clay particles. The results given in table 4 and 5 indicate that, with the addition of soil conditioners, silt and clay particles are aggregated to larger units which may further unite to form still larger aggregates.

TABLE 4

Flocculation of silt and clay

Treatment	Unaggregated silt and clay per 100 gm. soil	
	Heavy clay soil	Kneaded sandy loam
1. Untreated	12.2	26.2
2. Krilium (0.1%)	0.5	8.5
3. Poly-ack (0.1%)	2.8	—
4. Aerotil (0.1%)	9.7	—

TABLE 5

Water dispersion of soil having 31% clay

Treatment	Percentage of unaggregated soil particles after			
	1 min.	2 min.	5 min.	10 min.
1. Untreated	16.50	14.25	11.50	7.75
2. Krilium (0.1%)	11.00	8.50	5.75	3.50
3. Aerotil (0.1%)	9.75	8.50	5.50	4.75

Crumb formation : The surface soil should be crumbly and crumbs should be large enough not to be blown away by wind and they should also be stable to the action of water. This characteristic is very important where lot of wind or water erosions occur. Formation of larger aggregates by the application of krilium and aerotil in the surface soil to a depth of one inch resulted in the characteristic 'Crumb' formation, even in Delhi soil which is low in clay content. In both treated and untreated plots crumbs were formed by watering the plots with a rose-head can, then raking and drying the plots. On repeating a good crumbly structure was produced on the surface. When the plots were flood-irrigated, the soil crumbs in the treated plots were found resistant to the slaking effect of water while in the untreated plots, crumbs were broken down to form a smooth surface (Fig. 1, 2 and 3).

Water infiltration : Percolation rates for water infiltration were studied on treated and untreated soils on different sized aggregates. The data in table 6 indicate that, in case of krilium treated soils, the aggregates of the size of 1.5 mm. to 4 mm. are more stable and do not break down when the water precolates through them. While in case of untreated soil, most of the aggregates break down with the action of water and thus the pore spaces or channels are blocked and consequently the rate of percolation gets retarded. Thus krilium aids in improving drainage and aeration, both contributing to good root systems and better utilization of nutrients from the soil.

TABLE 6

Rate of water percolation through different sized aggregates

Treatment	Size of the aggregates	Amount of water percolates in 30 minutes
1. Untreated (6 inches soil column)	4 mm. to 6 mm.	162 cc.
	2.5 mm. to 4 mm.	140 cc.
	1.5 mm. to 2.5 mm.	111 cc.
	0.5 mm. to 1.5 mm.	66 cc.
2. Krilium (0.1%) (6 inches soil column)	4.0 mm. to 6.0 mm.	348 cc.
	2.5 mm. to 4.0 mm.	1020 cc.
	1.5 mm. to 2.5 mm.	459 cc.
	0.5 mm. to 1.5 mm.	240 cc.

Penetration : It has been noted during the course of present study that the soil conditioners are not capable of being leached down to the sub-soil and only cultural operations could physically carry them down to the lower layers. Krilium was applied to the soil only on the surface one inch layer and then it was alternately irrigated and dried three times. Samples were drawn from treated and untreated soils at 0 to 1 inch, 1 to 2 inches and 2 to 4 inches depths. The samples were then subjected to aggregate analysis by wet sieving and water dispersion. Increased percentage of aggregates was obtained only in the surface one inch layer of the treated soil, while other two layers were near to those of untreated soil. This shows that krilium gets fixed up with the soil particles wherever applied. Martin (1953), in his preliminary tests with C_{14} labelled polymers added to soil columns, also found that the polymer solution added on the upper portion and then leached acted very quickly but, did not move appreciably thereafter.

Water holding capacity : Water holding capacity of treated as well as untreated soils was determined. Three soils were selected for this purpose, a good structured loamy soil, an alkali soil and a sandy loam. In case of soil having good structure, the water holding capacity has not increased to that extent as in case of dispersed alkali soil.

Fig. 1.—Soil without any soil conditioner

Fig. 2.—Soil treated with soil conditioner Krilium

Fig. 3.—Soil treated with soil conditioner Aerotil

However, treated soils have shown increases in water holding capacity over untreated soils in all the cases but the increase is not very significant.

TABLE 7

Water holding capacity

Soil type	Treatment	Water holding capacity per 100 gms. of soil
Loamy soil having good structure	Untreated	46.9
	Krilium (0.1%)	48.3
	Aerotil (0.1%)	47.5
Dispersed alkali soil	Untreated	36.8
	Krilium (0.1%)	42.0
	Aerotil (0.1%)	41.8
Sandy loam	Untreated	43.1
	Krilium (0.1%)	46.2
	Aerotil (0.1%)	45.6

Destruction of aggregates: Two soils, a clay loam (black soil) and a sandy loam were treated with krilium formulation No. 6 (Vinylacetate maleic acid compound) at the rate of 0.2 percent and made into aggregates larger than ½ an inch. After drying, the aggregates were ground and then made into aggregates a second time without further addition of krilium. On testing both types of aggregates for their stability to the action of water, it was found that grinding completely destroyed the effect of krilium. (Table 8). Laws (1954) also found similar results with clayey soils.

TABLE 8

Destruction of aggregates

Soil type	Percentage of water stable aggregates		
	Krilium treated	Krilium treated and ground	Untreated
Clay loam (Black soil)	89.0	45.1	53.0
Sandy loam	74.6	14.4	16.3

EFFECT OF KRILIUM ON SALINE AND ALKALI SOILS

To study the effect of krilium on the physical condition of a dispersed alkali soil, a soil with high pH and high exchangeable sodium was collected for the experiment. The soil passing through 0.5 mm sieve was dispersed in water with and without the addition of krilium and gypsum. After 24 hours, the samples were shaken 20 times with upward and downward movements and the soil suspensions were pipetted out at 10 cm. depth after one minute, two minutes, five minutes, 10 minutes and 8 hours intervals. In another experiment, of the treated and untreated soils, artificial aggregates were prepared, which passed through 6 mm. sieve and were retained on 4 mm. sieve. These aggregates were dried and then subjected to wet sieving on a 0.25 mm. sieve. The results (Tables 9 and 10) indicate that, in dilute suspensions, as the soil particles are far apart due to their dispersed nature, krilium is not so effective in flocculating the sodium soil. With the addition of

gypsum when the sodium soil is converted into calcium soil, krilium seems to be very effective. When the soil is closely packed, krilium is able to cement the particles, even of the sodium soil to form aggregates which were found stable by wet sieving.

TABLE 9

Water dispersion of alkali soil

Treatment	Dispersed soil particles per 100 g. of soil after				
	1 min.	2 min.	5 min.	10 min.	8 hr.
1. Untreated	35.75	31.75	27.75	25.75	19.25
2. Krilium (0.1%)	32.00	26.25	24.00	21.75	14.25
3. Gypsum (1.0%)	30.75	25.75	21.50	14.50	nil
4. Krilium & gypsum	5.50	4.00	4.00	3.50	nil

TABLE 10

Aggregate analysis of alkali soil

Treatment	Percentage of aggregates larger than 0.25 mm.
1. Untreated	0.4
2. Krilium (0.1%)	20.1
3. Gypsum (1.0%)	1.8
4. Krilium & gypsum	22.0

During the process of reclamation when a saline-alkali soil is flooded to leach out the excessive soluble salts, it is generally seen that the physical condition of the soil deteriorates to a great extent by the dispersed nature of the sodium soil. To ameliorate this defect with the application of krilium, laboratory studies were made. A saline-alkali soil (high salts and high exchangeable sodium) was treated with 0.1% krilium and the salts were washed out by successive leachings in a funnel. The soil was then transferred to a cylinder for dispersion with water. The results of suspensions pipetted out at 10 cm, depth (Table 11) indicate that when a sodium soil is in a flocculated condition due to the presence of excess soluble salts, the addition of krilium binds the soil particles to such an extent that they are not easily dispersed even when the soluble salts are removed. This is very useful in improving the permeability of saline and alkali soils resulting in better drainage and easy leaching out of the soluble salts. This has also been verified in another way. Ten gm. of an alkali soil was shaken in 500 cc. water. The dispersed soil particles pipetted out showed 28.0% of silt and clay and 21.1% of clay in untreated and 16.75 of silt and clay and 9.5% of clay in krilium treated soil. To both the treated and untreated suspensions, just the sufficient quantity of sodium chloride was added to flocculate the soil particles. In both the suspensions, supernetant liquids were decanted off and the volume again made to 500 cc. with distilled water. It was noticed that the untreated soil was again dispersed when the sodium chloride concentration was reduced to below 1 mmho/cm. in terms of electrical conductivity. But at the same salt concentration, the suspension of krilium treated soil soon became clear as the aggregated soil particles were settling very rapidly. This shows that once the aggregation is brought about by krilium in a sodium soil, it is not easily dispersed in water.

TABLE 11

Water dispersion of saline-alkali soil treated with Krilium and leached

Treatment	Dispersed soil particles per 100 gms. of soil after			
	1 min.	2 min.	5 min.	10 min.
Untreated	25.0	17.50	12.75	11.25
Krilium (0.1%) treated	12.5	6.75	4.00	3.75

Studies are being continued on saline-alkali and nonsaline-alkali soils. Effect of different soil conditioners on different soil types with varying physical and chemical composition are also being studied.

As regards the plant response, preliminary pot culture experiments have indicated a likely increase in yield of 'Kangni' (*Setari italica*). Experiments on radish have indicated that the soil conditioners are to be applied to deeper layers to obtain any substantial increase in the yield of root crops. Effect on treatment with krilium was partially lost in the second crop season, this was probably the result of working the soil for refilling the pots.

SUMMARY

Three soil conditioners namely krilium, aerotil and poly-ack were studied with the object of assessing their effects on soil structure and allied properties of soil, *e.g.*, aggregation, water infiltration, and water holding capacity. All the three soil conditioners proved to be effective as flocculating and aggregate-stabilizing agents. When conditioners were applied at rates of 0.05 to 0.1 per cent to different soils, the aggregation as determined by wet sieving was increased, and other characteristics commonly associated with good structure were developed. Water holding capacity of the treated soils was only slightly increased. Soil conditioners were found to be effective in bringing about increased aggregation when applied to dispersed sodium soils and this is a very important factor from the point of view of reclaiming saline and alkali soils.

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The Study of Na^+/K^+ Reversibility on Clay Membrane Electrodes

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The use of clay membrane electrodes for the measurement of cation activities has been emphasised by Marshall and co-workers (1955), Chatterjee (1949) and Mitra and Chatterjee (1953) and Mitra (1954). According to Marshall it has been found expedient to consider the clay membrane as a cationic reversible electrode. If such a membrane separates two solutions having different cationic cativities, the e. m. f. observed should be equal to that given by the Nernst equation, provided the membrane is perfectly reversible. Working with a large number of electrodes, it has been found (Mitra and Chatterjee, 1953) that a correspondence such as one mentioned above is usually obtained in moderately dilute solutions. The exact reason for this peculiar behaviour is not of course quite clear, but it has been possible to characterise the membrane by two quantities: (i) the charge on the membrane surface, and (ii) the mobility ratio of the cations (*cf.* below). The present paper is concerned with the sodium-potassium ion reversibility and an evaluation of the mobility ratio of these cations using different types of membranes. It also reports the results of some experiments on the determination of activities of each of the ions in a mixture of Na^+ and K^+ ions.

EXPERIMENTAL

An examination of the influence of charge on the membrane surface on its overall performance as an electrode suggested that the charge should be as high as possible. Consequently, the choice of the membrane material was restricted to montmorillonitic clays. In order to impart suitable physical as well as electrochemical properties thin membranes prepared by evaporating a suspension of the clay were heated for 24 to 48 hours to various temperatures ranging from 500-700°C (Mitra and Chatterjee, 1953). The clays have been effectively replaced by synthetic ion exchange resins by Wyllie and Patnode (1950), and Sinha (1954). The resin membranes are more conveniently prepared by mixing the finely divided resins with a suitable amount of an inert binder resin and hot-compressing them into the desired thinness (*loc. cit.*)

The membranes thus prepared were affixed to one end of a small Pyrex tubing by means of Durofix adhesive. They were tested with solutions of NaCl and KCl having known cationic activities. This includes the determination of asymmetry potential, if any. Those showing no or negligible asymmetry potential were used for the determination of activities and mobility ratios. For this purpose the membranes were allowed to separate two solutions, one of NaCl and another of KCl having known a_{Na} and a_K respectively. The e. m. f.'s were measured with the help of a Cambridge potentiometer in combination with a Leeds and Northrup galvanometer, having a current sensitivity of 10^{-8} amps.

RESULTS AND DISCUSSIONS

From the observed e. m. f. between two micro calomel electrodes placed in these solutions the mobility ratio may be calculated from the relationship,

$$E=\frac{RT}{F} \ln \frac{a_K}{a_{Na}} \cdot \frac{U_K}{U_{Na}}$$

where E is the observed e. m. f. in volts and U_K/U_{Na} the mobility ratio. The values of U_K/U_{Na} so calculated are given in table 1. The ions are assumed to move with different speeds inside the membrane, and hence the correction term, viz., U_K/U_{Na} so to say, to the Nernst equation. This would possibly be true for ion-permeable membranes. The clay membranes are not permeable in the sense envisaged above and as such the observed e. m. f. may be related to what may be termed the standard electrode potentials on the two sides of the membrane, thus,

$$E = E^\circ_{Na} - E^\circ_K + \frac{RT}{F} \ln \frac{a_K}{a_{Na}}$$

$$= E^\circ_{Na,K} + \frac{RT}{F} \ln \frac{a_K}{a_{Na}}$$

where $E^\circ_{Na,K} = E^\circ_{Na} - E^\circ_K$ is the standard free energy change of the reaction : K-membrane + $Na^+ \rightleftharpoons$ Na-membrane + K^+. This, like the mobility ratio to which it is mathematically related, becomes a characteristic quantity of the membrane itself. These data are also given in table 1.

TABLE 1

Membranes	a_K/a_{Na} $\frac{.009}{.00877}$			$\frac{.027}{.0263}$			$\frac{.081}{.0789}$		
	E.m.f. in mv	$E^\circ_{Na,K}$ in mv	U_K/U_{Na}	E.m.f. in mv	$E^\circ_{Na,K}$ in mv	U_K/U_{Na}	E.m.f. in mv	$E^\circ_{Na,K}$ in mv	U_K/U_{Na}
A.* IONAC (200)	13	12.3	1.618	18	17.3	1.966	16	15.3	1.820
B. K.H.5 (1)	45	44.3	5.640	46	45.3	5.866	44	43.3	5.424
C. K.H.5 (3)	46	45.3	5.866	46	45.3	5.866	45	44.3	5.639
D. T.C.6 (2)	22.5	21.8	2.350	23.5	22.8	2.437	20.5	19.8	2.168
E. A.H.5 (2)	38.5	37.8	4.380	40	39.3	4.639	35	34.8	3.818

*A is a synthetic resin membrane and B to E are clay membranes.

TABLE 2

Sodium and potassium ion activities in a mixture of the two ions

$a_K = .003$ (inside) ; $a_{Na} = .00584$ & $a_K = .001$ (outside)

Membranes	U_K/U_{Na}	E.m.f. (mv)	Calc. a_{Na} from
A. IONAC(200)	1.618	9.5	(A-B) 0.00569
B. K.H.5(1)	5.640	−12.5	(B-D) 0.00596
C. K.H.5(2)	5.866	−10.0	
D. T.C.6(2)	2.350	4.5	(A-C) 0.00511
E. A.H.5(2)	4.380	− 5.5	(A-E) 0.00512

TABLE 2—*Contd.*

$a_K = .009$ (inside); $a_{Na} = .01754$ & $a_K = .001$ (outside)

Membranes	U_K/U_{Na}	E.m.f. (mv)	Calc. a_{Na} from
A. IONAC(200)	1.618	8	
B. K.H.5(1)	5.640	−21	(B-D) 0.01700
C. K.H.5(3)	5.866	−19	(D-E) 0.01643
D. T.C.6(2)	2.350	− 2	(C-D) 0.01539
E. A.H.5(2)	4.380	−15.5	(A-E) 0.01643

$a_K = .027$ (inside); $a_{Na} = 0.01754$ & $a_K = .001$ (outside)

Membranes	E.m.f. (mv)	Calc. a_{Na} from
A. IONAC(200)	−20.0	(A-B) 0.023
B. K.H.5(1)	−47.5	(B-D) 0.01696
C. K.H.5(3)	−47.5	(D-E) 0.01712
D. T.C.6(2)	−30.0	(D-C) 0.01631
E. A.H.5(2)	−43.5	

Except for the slight irregular variation of the mobility ratios with the activities of the ions they may be regarded as constant as they are expected to be. While applying these values of mobility ratios for measurement of unknown activities it is found expedient to use as far as possible the exact mobility ratio in the particular activity range in which it has been evaluated, instead of using an average value. The resin membrane has the least value of the mobility ratios perhaps because it has an 'open' structure, whereas those of the more compact clay membranes vary from about 2.2 to 5.9.

Determination of Na *and* K *ion activities in a mixture of the two :* As already explained, the mobility ratio acts, as it were, as a correction term to the Nernst equation. It probably arises from the difference in the speed of the ions inside a permeable membrane or in the exchangeability of the ions on the electrode surface. In a mixture of the two ions in solution e. g., Na^+ and K^+, it is assumed that their relative effect on the electrode surface is determined by their mobility ratio. Consequently, two simultaneous equations given below can be formed from the observed e.m.f.'s of a cell composed of two different membranes separating a mixture of K and Na ions and a solution of known a_K or a_{Na}.

$$E_1 = \frac{RT}{F} \ln \frac{a_K^{II}}{a_{Na}^{I}\left(\frac{U_{Na}}{U_K}\right)_1 + a_K^{I}}\ ; \quad E_2 = \frac{RT}{F} \ln \frac{a_K^{II}}{a_K^{I}\left(\frac{U_{Na}}{U_K}\right)_2 + a_K^{I}}.$$

Knowing E_1, E_2, a_K^{II} and $(U_{Na}/U_K)_1$ and $(U_{Na}/U_K)_2$, a_K^{I} and a_{Na}^{I} may be evaluated. Table 2 gives the results of these calculations with known mixtures of Na and K ions.

The agreement appears to be fairly satisfactory considering the sensitive nature of the function between E and activity ratio. On the basis of this agreement the measure-

ments of individual activities of ions in the mixtures may be extended to unknown systems and heteroionic colloidal clays.

SUMMARY

Mobility ratios of Na and K ion pair in clay and resin membrane electrodes were determined from e.m.f. measurements of cells constituted of the membranes separating two solutions having known activities of Na and K ions. The value of the mobility ratio, which may be regarded as a correction term to the Nernst equation, remains fairly constant for a particular membrane electrode over the activity range used to evaluate them. Membranes having sufficiently different mobility ratios have been used to measure the potential difference between solutions containing on one side a mixture of Na and K ions and on the other, either K or Na ions; from the observed e.m.f.'s with any two membranes the activity of each of the ions in the mixture was calculated. The agreement between the calculated and actual values of activity was fairly satisfactory.

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Pusa Permanent Manurial Experiment (New Series)

Studies of the Maize Yields in Relation to the Preceding Crops in the Rotation

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The permanent manurial experiments (new series) were started at Pusa (Bihar) in the year 1932 with a view to determining under sub-tropical climatic conditions, the specific effects on soil fertility of the more important organic manures and inorganic fertilizers applied alone and in various combinations to crops grown in a rotation. The experiments were laid out in ten randomized blocks with ten treatments as given below. The net plot size was 37.5 ft. × 18 ft. (1/64.53 acre).

A. No manure (control)

B. Farmyard manure at 8000 lb. per acre = 40 lb. of N per acre (total amount applied in the last week of April or first week of May).

C. Rape-cake at 40 lb. N per acre (half applied just before maize sowing and half applied at the last interculture of maize).

D. Sulphate of ammonia at 40 lb. N per acre

E. Sulphate of potash at 50 lb. K_2O per acre

F. Superphosphate at 80 lb. P_2O_5 per acre

G. Sulphate of potash at 50 lb. K_2O + superphosphate at 80 lb. P_2O_5 per acre

H. Sulphate of ammonia at 40 lb. N + sulphate of potash at 50 lb. K_2O + superphosphate at 80 lb. P_2O_5 per acre

I. Sulphate of ammonia at 40 lb. N + superphosphate at 80 lb. P_2O_5 per acre

J. Sulphate of ammonia at 40 lb. N + sulphate of potash at 50 lb. K_2O per acre

The inorganic fertilizers, alone and in various combinations, were applied half before *kharif* sowing and half before *rabi* sowing.

The system of cropping followed was a four-year eight-course rotation with the maize crop in *kharif* preceded by four *rabi* crops, *viz* oats, peas, wheat and gram in succession.

The soil of Pusa is Gangetic alluvium, mostly light loam and highly calcareous in nature. The total nitrogen content varies from 0.032 to 0.045 per cent, organic carbon from 0.26 to 0.37 per cent, while the available P_2O_5 contents are 0.0039 to 0.0068 per cent. The calcium carbonate content is very high, being 35 to 40 per cent. The pH of the soil is 8.0 to 8.1.

The crops in North Bihar are grown under rainfed conditions. No irrigations were given to any of the crops in this experiments. The average monthly and annual rainfall during 20 years from 1932-33 to 1951-52 were as follows:

Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Av. per annum*
0.56	0.82	0.29	0.46	1.97	6.80	10.95	11.39	8.50	2.35	0.15	0.05	44.20 inches

Treatment comparisons in individual cycles

The proper unit of study of changes in productivity under continuous manurial treatments would be a complete cycle of four years. An attempt has, therefore, been made to analyse the data based on five cycles over a period of twenty years from 1932-33 to 1951-52. The maize yields of each plot were accordingly pooled over the four phases of each cycle and the pooled yields were subjected to statistical analysis. The analysis of variance worked out separately for each cycle indicated highly significant differences among the various treatments. The results of the analysis are summarised cycle-wise, in table 1.

Table 1

Average yields of maize in maunds per acre under different treatments cycle-wise

Treatments	First cycle	Treat-ments	Second cycle	Treat-ments	Third cycle	Treat-ments	Fourth cycle	Treat-ments	Fifth cycle
C	14.85	C	10.59	C	10.50	C	4.73	C	5.79
I	11.19	I	8.05	B	9.09	B	4.37	B	4.76
H	11.06	B	7.93	H	8.55	H	3.59	I	4.11
B	10.60	H	7.27	I	8.33	J	3.45	D	3.93
J	9.90	D	6.18	D	7.16	I	3.36	H	3.88
D	9.51	J	5.82	J	6.84	D	3.22	J	3.83
F	8.21	F	4.09	F	5.30	F	2.30	E	2.53
E	7.77	E	3.62	E	4.52	E	2.06	F	2.52
A	7.38	G	3.21	G	4.30	A	1.76	G	2.47
G	6.91	A	2 96	A	4.16	G	1.69	A	2.17
S. Em	±0.66		±0.42		±0.61		±0.26		±0.36
C. D. at 5 per cent	1.85		1.19		1.72		0.72		1.01
C. D. at 1 per cent	2.46		1.58		2.28		0.95		1.33

It will be observed from the above table that the order of the treatments is practically the same under each cycle, though the yields fall off under each treatment from cycle to cycle. The treatment C (rape-cake) has given the highest yield in each cycle, and is significantly superior to the other nine treatments in the first, second and fifth cycles. The difference between the treatments C (rape-cake) and B (farmyard manure) is, however, not significant in third and fourth cycles, but the treatment C (rape-cake) differs significantly from the other eight treatments. The treatments B (farmyard manure), H (npk) and I (np), which in four out of five cycles do not differ significantly among themselves, have shown better performance than the treatments F (p), E (k), A (control) and G (pk). The lowest yields are given by the treatments F (p), E (k), A (control) and G (pk) and the differences among them are not significant. The treatments D (n) and J (nk) lie in between the two groups of the treatments, *viz.*, (i) C (rape-cake), B (farmyard manure), H (npk) and I (np) and (ii) F (p), E (k), A (control) and G (pk). These two treatments do not differ significantly from the treatments H (npk) and B (farmyard manure) in the first cycle, from the treatments H (npk) and I (np) in the third and fourth cycles and from the treatments H (npk) and I (np) and B (farmyard manure) in the fifth cycle, but these have come out significantly better than the treatments F (p), E (k), A (control) and G (pk) in the second, fourth and fifth cycles.

(i) *Significance of main effects and interactions of nitrogen (N), phosphorus (P) and potash (K):* Table 2 shows the main effects and interactions of N, P and K in maunds per acre with proper signs.

TABLE 2

Main effects and interactions of N, P and K in maunds per acre cycle-wise

Effects	First cycle	Second cycle	Third cycle	Fourth cycle	Fifth cycle
N	2.84**	3.36**	3.16**	1.46**	1.52**
P	0.70	1.02**	0.96*	0.12	0.14
NP	0.72	0.66*	0.50	0.02	−0.02
K	−0.16	−0.34	−0.18	0.04	−0.006
NK	0.30	−0.24	0.14	0.20	−0.16
PK	−0.56	−0.50	−0.20	−0.22	−0.14
NPK	0.30	0.28	0.48	0.22	0.08
S.E.	±0.46	±0.28	±0.44	±0.18	±0.26

* Significant at 5 per cent
** Significant at 1 per cent

It will be seen that the response to nitrogen is positive and highly significant under each cycle. The response to phosphorus is positive and also significant under the second and third cycles and the interaction NP is significantly positive in the second cycle only. The other main effects and interactions are not significant. Potash and the interaction PK have given indications of depressing effects, though not conclusive.

(ii) *Significances of linear regression of yield on cycles :* Table 3 gives the analysis of variance for testing the significance of linear regression for each treatment separately.

TABLE 3

Testing of linear regression of maize yields on cycles separately for each treatment

	Degrees of freedom	Mean sum of squares	Variance ratio	Mean sum of squares	Variance ratio
		Treatment A		*Treatment B*	
Linear regression	1	879.45	290.25**	1510.53	57.76**
Error	9	3.03		26.15	
		Treatment C		*Treatment D*	
Linear regression	1	3733.64	250.58**	1300.32	114.26**
Error	9	14.90		11.38	
		Treatment E		*Treatment F*	
Linear regression	1	941.94	51.03**	1127.62	62.44**
Error	9	18.46		18.06	
		Treatment G		*Treatment H*	
Linear regression	1	705.17	76.73**	2114.44	112.89**
Error	9	9.19		18.73	
		Treatment I		*Treatment J*	
Linear regression	1	2313.13	176.57**	1367.41	172.65**
Error	9	13.10		7.92	

**Significant at 1 per cent

It is seen from the table that the linear regression for all the treatments is highly significant.

(iii) *Comparison of linear regression coefficients of yield on cycles :* The analysis of variance to test the differences between the regression coefficients of different treatments is given in table 4.

TABLE 4

Analysis of variance to compare regression coefficients of maize yields on cycles

	Degrees of freedom	Mean sum of squares	Variance ratio
Blocks	9	55.32	5.81**
Treatment regressions	9	108.08	11.36**
Error	81	9.51	

**Significant at 1 per cent

The analysis indicates significant differences between the regression coefficients. The results are given in table 5.

TABLE 5

Linear regression coefficients of maize yields on cycles (maunds per acre)

Treatments	Linear regression coefficients
C	−2.40
I	−1.88
H	−1.80
B	−1.52
J	−1.45
D	−1.41
F	−1.32
E	−1.20
A	−1.17
G	−1.04
S. E.	±0.12
C. D. at 5 per cent	0.34
C. D. at 1 per cent	0.45

It will be observed from table 5 that the regression coefficients have got negative values for all the treatments. It indicates that the yields deteriorate under each treatment from cycle to cycle. The coefficient for the treatment C (rape-cake) has the highest negative value and it differs significantly from the other nine treatments. The differences between the regression coefficients for the treatments I(np) and H(npk) as well as for the treatments H(npk) and B (farmyard manure) are not significant, but the coefficient of the treatment I (np) is significantly greater than those of the treatments J (nk) to G (pk). The regression coefficient of the treatment B (farmyard manure) does not differ significantly from those of the treatments J (nk), D (n), F (p) and E (k), and the coefficients of the treatments F (p), E (k), A (control) and G (pk) do not differ significantly among themselves and have comparatively smaller rate of deterioration.

(iv) *Linear regression coefficients for main effects and interactions*: The linear regression coefficients for main effects and interactions of nitrogen (N), phosphorus (P) and potash (K) are indicated in table 6.

TABLE 6

Linear regression coefficients for main effects and interactions in maunds per acre

Effects	Regression coefficients
N	−0.4526**
P	−0.2026*
NP	−0.2076*
K	0.0726
NK	−0.0526
PK	0.1076
NPK	−0.0476
S. E	±0.0856

*Significant at 5 per cent   **Significant at 1 per cent

It will be seen from the above table that the rate of deteriorotion is highly significant for the main effect N (nitrogen) and significant for the main effect P (phosphorus) and interaction NP. The other main effects and interactions do not have significant rate of deterioration.

ANALYSIS OF TOTAL MAIZE YIELDS AFTER PRECEDING RABI CROPS IN THE ROTATION

The totals of maize yields after oats, peas, wheat and gram obtained separately from each plot, have been analysed to compare the average carry over effects of different treatments, partly applied to the *rabi* crops and the effects of the preceding *rabi* crops which were inevitably compounded with the effect of direct manuring partly applied to the *kharif* crop of maize. The analysis of variance indicated highly significant differences among treatments. The results are summarised in table 7.

TABLE 7

Average maize yields after different crops in the rotation in maunds per acre

Treatments	Maize after oats	Treatments	Maize after peas	Treatments	Maize after wheat	Treatments	Maize after gram
C	7.97	C	7.30	C	8.49	C	11.79
B	5.76	B	5.62	B	7.22	B	9.28
I	5.46	D	5.59	H	6.94	I	8.45
H	5.23	H	5.54	I	6.85	H	7.93
J	4.19	I	5.53	J	6.14	D	6.74
D	3.97	J	5.39	D	5.74	J	6.03
F	2.94	F	3.59	F	4.24	F	5.30
E	2.72	E	3.33	E	4.08	E	4.25
A	2.31	A	2.86	A	3.90	G	4.09
G	2.20	G	2.84	G	3.90	A	3.61
S. Em	±0.33		±0.41		±0.41		±0.57
C. D. at 5 %	0.94		1.14		1.14		1.62
C. D. at 1 %	1.25		1.51		1.51		2.14

Maize after oats: It is observed that the treatment C (rape-cake) has given the highest yield. The next best treatments are B (farmyard manure), I (np) and H (npk); the differences among them are not significant. The treatments J (np) and D (n) also do not differ significantly from each other, but are significantly better than the treatments F (p), E (k), A (control) and G (pk) which themselves do not differ significantly among themselves.

Maize after peas: The treatment C (rape-cake) has given significantly the best yield. The next best treatments are B (farmyard manure), D (n), H (npk), I (np) and J (nk); these do not differ significantly among themselves, but are superior to the treatments F (p), E (k), A (control) and G (pk) and the differences among them are not significant.

Maize after wheat: The treatment C (rape-cake) has significantly raised the yield. The treatments B (farmyard manure), H (npk), I (np), and J (nk) do not differ significantly among themselves, but the treatments B (farmyard manure) and H (npk) are significantly superior to the treatments D (n), F (p), E (k), A (control) and G (pk). The differences among the treatments I (np), J (nk) and D (n) are not significant, but all of them are significantly better than the treatments F (p), E (k), A (control) and G (pk), which among themselves do not differ significantly.

Maize after gram: The treatment C (rape-cake) has in this case also established its superiority over other treatments. Next, the treatments B (farmyard manure), I (np) and H (npk) follow; the differences among these are not significant. The treatments B (farmyard manure) and I (np) are, however, significantly superior to the treatments D to A. The differences among the groups of treatments (*i*) H (npk) and D (n), (*ii*) D (n), J (nk) and F (p), (*iii*) F (p), E (k) and G (pk) and (*iv*) E (k), G (pk) and A (control) are not significant. The treatment H (npk) is significantly better than the treatments J (nk), F (p), E (k), G (pk) and A (control).

(i) *Significance of main effects and interactions of nitrogen (N), phosphorus (P) and potash (K)*: The analysis of variance indicated significant main response of maize yield to N (nitrogen) under the different preceding crops. It also indicated the main effect to P (phosphorus) to be significant for maize yields after oats and gram and interaction NP to be significant for maize yields after oats only. The results are shown in table 8.

TABLE 8

Main effects and interactions of N, P and K in maunds per acre

Effects	Maize after oats	Maize after peas	Maize after wheat	Maize after gram
N	2.18**	2.34**	2.38**	2.96**
P	0.66**	0.08	0.52	1.30**
NP	0.60*	−0.04	0.44	0.52
K	−0.08	−0.12	0.08	−0.46
NK	0.08	0.02	0.16	−0.16
PK	−0.40	−0.26	−0.20	−0.42
NPK	0.18	0.36	0.06	0.50
S. E.	±0.24	±0.28	±0.28	±0.40

*Significant at 5 per cent
**Significant at 1 per cent

Table 8 reveals that the main effect N is throughout positive and significant, whereas P is positive and significant in the case of maize yields after oats and gram, and interaction NP is positively significant only for maize yields after oats. The effects K and PK are not significant, but they have negative values in majority of the cases. The interactions NK and NPK are not significant, but have given positive effects, except in the case of maize yields after gram where NK has negative value.

(ii) *Combined analysis of maize yields after diffrenent rabi crops in the rotation :* The statistical analysis of maize yields after oats, peas, wheat and gram showed highly significant differences. The results are summarised in table 9.

TABLE 9

Average yields of maize after different crops in the rotation

Preceding crops	Yield of maize in maunds per acre
Oats	4.28
Peas	4.76
Wheat	5.75
S. Em.	±0.15
C. D. at 5 per cent	0.44
C. D. at 1 per cent	0.59
Gram	6.75
S. Em	±0.17
C. D. at 5 per cent	0.47)*
C. D. at 1 per cent	0.63)

* For comparing average maize yield after gram with average maize yields after oats, peas and wheat, since there were only four maize crops after gram and five after other crops in the rotation.

It will be observed from table 9 that the average maize yield after gram is significantly superior to the average maize yields after oats, peas and wheat. Next, it will be seen that the average maize yield after wheat is significantly superior to the average maize yield after peas and oats. The difference in the average maize yield after peas and oats is not significant at 1 per cent level of significance, but at 5 per cent level the average maize yields after peas is significantly better than that after oats. It can thus be inferred that the maize yield has been the best after gram.

DISCUSSION

Analysis of total maize yields in successive rotations : The statistical analysis of pooled yields of maize in different cycles showed highly significant differences among the treatments. All the ten treatments registered the highest yields in the first cycle and then fell off considerably from cycle to cycle under each treatment. The order of the treatment is, however, practically the same in each cycle. The rape-cake treatment has given the highest yield throughout and is significantly superior to the remaining nine treatments in the first, second and fifth cycles. The difference between rape-cake and farmyard manure treatments is not significant in the remaining two cycles. It is, therefore, interesting to note that rape-cake has been very effective.

The treatments farmyard manure, npk, and np have also given significantly better yields than the treatments p, k, control and pk in each cycle which have on the contrary shown poor effects. The treatments n and nk occupy intermediate position ; these two treatments do not differ significantly from farmyard manure, npk and np treatments in

the fifth cycle, and at the same time have come out significantly better than the treatments p, k, control and pk.

Significance of main effects and interactions of nitrogen (N), phosphorus (P) and potash (K) : It will be seen from table 2 that the main response to N is highly significant and positive under each cycle, but the response to P is significant and positive under the second and third cycles only. K as usual has negative effect, though non-significant. Among the interactions, NP alone is significant under second cycle. This indicates, therefore, that for maize nitrogen alone is much more beneficial than any other nutrients.

Significance of linear regression of yield on cycles : The study of linear regression coefficients of the maize yields on cycles points out that the rate of deterioration is highly significant under all the treatments. The rate of deterioration is highest for rape-cake. The treatments farmyard manure, np, npk, n and nk showed greater rate of deterioration as compared with the treatments p, k, control and pk. It can thus be observed that the treatments which have given higher yields, showed higher rate of deterioration and *vice versa.*

Analysis of total maize yields after preceding rabi crops in the rotation : An examination of total yields after different preceding crops revealed that the rape-cake treatment was very effective after each crop. Next to it, was farmyard manure followed by the combinations of sulphate of ammonia and superphosphate (np) and sulphate of ammonia, superphosphate and sulphate of potash (npk) which raised the yields after each crop, but k alone and in combination with p gave poor yields. All the treatments, in general, yielded well after gram.

The main response to N (nitrogen) was found to be highly significant and positive after each crop. The maize yields after oats and gram gave significantly positive response to phosphorus, but the responses after peas and wheat, though positive, were not significant. Potash alone and PK had a negative effect after each crop, but not significant.

Average maize yields after different rabi crops in the rotation : The highest average yield of maize to the extent of 6.75 maunds per acre was obtained after gram.

SUMMARY

In this paper an attempt has been made to study the maize yield data from the Pusa Permanent Manurial Experiments (New Series) based on five cycles over a period of twenty years from 1932-33 to 1951-52.

The maize yields for four years in each cycle of crop rotation were pooled, and the pooled yields of different cycles were statistically analysed with a view to studying the effects of treatments after allowing for the effect of preceding crop on the maize yield. Further, the maize yields after oats, peas, wheat and gram (the crops occuring in the 4-year rotation) were statistically analysed to compare the average carry over effects of different treatments partly applied to the *rabi* crops and the effects of the preceding *rabi* crops which were inevitably compounded with the effects of direct manuring partly applied to the *kharif* crop of maize.

The study revealed the following findings :

1. The rape-cake treatment was found to be very effective, but showed a high rate of deterioration.

2. Farmyard manure, complete fertillizer (npk) and np gave significantly better yields than superphosphate, sulphate of potash and control in each cycle, and had a medium rate of deterioration.

3. Ammonium sulphate alone did not give better performance as compared to np or npk treatments, though it was better than the control.

4. The main response to N (nitrogen) was highly significant and positive under each cycle. Response to P (phosphorus) was seen only in two cycles, but K did not show any effect.

5. All the treatments yielded well after gram, but the rape cake treatment was very effective after each crop.

6. Farmyard manure, npk and np also raised the maize yields after each crop, next to rape-cake.

7. The response to N (nitrogen) was highly significant and positive after each crop. Response to P (phosphorus) was evident after oats and gram, but K (potash) had no effect.

8. Maize yield after gram was significantly the best.

ACKNOWLEDGMENTS

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Studies on the Response Curve of Nitrogen on Wheat

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In the past, attempts have been made to study the effect of some particular dose of nitrogenous fertiliser on wheat, but there appears to be no evidence, at least in India, when work was undertaken to find out the response of wheat to increasing doses of nitrogen and thus work out optimum and economic doses for wheat. Stewart (1947) in his report on the soil fertility investigations in India has stressed the importance and need for the study of response curves of nitrogen.

It was, therefore, considered necessary as early as 1949 to undertake investigations on 'Response curve of nitrogen'. Accordingly, an experiment was laid out in 1950-51 to study the response curve of nitrogen for wheat and to work out the optimum and economic doses for wheat. The results obtained during the period of three years *i.e.* 1950-53 are summarised and reported in this communication.

EXPERIMENTAL

An experiment on 'Response curve of nitrogen on wheat' was started in 1950-51 and is still in progress. The details for 3 years *i.e.*, 1950-51, 1951-52 and 1952-53 are as under :

	1950-51	1951-52	1952-53
Location :	Main block 5 D—E	Main block 5 D—E	Main block 7 E—F
System of layout :	Randomised block	Randomised block	Randomised block
No. of replications :	8	8	8
Size of plot (Net harvested)	0.0141 acre	0.0141 acre	0.0141 acre

Treatments : The treatments were same in all the three years as given below.

	N	P	K
A —	0	0	0
B —	0	60	40
C —	10	60	40
D —	20	60	40
E —	30	60	40
F —	40	60	40
G —	50	60	40
H —	60	60	40
I —	70	60	40
J —	80	60	40
K —	90	60	40
L —	100	60	40

Climate : During 1950-51 and 1952-53, it was fairly normal. During 1951-52, climatic conditions were otherwise normal excepting that there was an unprecedented hailstorm in March.

Soil :	*pH*	*Nitrogen %*	*Available P_2O_5 %*
Main block 5 D & E	8.0-8.1	0.041-0.046	0.0096-0.0155
Main block 7 E & F		0.052	0.014

Variety : C-518 which is known to grow successfully under very high fertility conditions was selected for study.

Fertilizers : Phosphate and potash were given as a basal dose so that these may not prove limiting factor in response of nitrogen. Phosphate and potash were applied at the time of sowing. Nitrogen as sulphate of ammonia was applied as top dressing with the first irrigation which was about 7 to 8 weeks after sowing.

Cultural treatments : All the cultural treatments and irrigations were nearly the same during all the three years.

Study of economics : Attempt has been made to study economics of different treatments. Economics of different doses of nitrogen have been studied in presence of PK and in its absence. In working out the economics, the cost of fertilizers, labour involved in the application of fertilizer and the threshing and cleaning of extra yield were considered. The extra cost thus obtained is deducted from the value of extra yield obtained over the control A and control B as the case may be and net profit and loss worked out. In working out cost and value, the following rates were used.

Price for wheat grain	Rs. 16/- a maund
Price for wheat straw	Rs. 1/8 a maund
Cost of nitrogen	Re. 1/- per lb.
Cost of P_2O_5	Re. -/9 per lb.
Cost of K_2O	Re. -/7.3 per lb.
Cost of threshing and cleaning one maund of grain ...	Rs. 2/- a maund
Labour involved in application of fertilizers	Rs. 1/8 per acre

RESULTS AND DISCUSSION

The findings have been grouped into four main groups as under :—(i) yield of wheat grain, (ii) response, (iii) economics and (iv) quality of grain.

Yield of wheat grain : The results obtained each year were analysed separately. Serial analysis was also carried out to study the aggregate response of nitrogen over the period of three years. The results of the statistical analysis and average yields are tabulated in tables 1 to 4.

TABLE 1

Analysis of variance

Source	D. F.	1950-51		1951-52		1952-53	
		Mean sum of squares	Variance ratio	Mean sum of squares	Variance ratio	Mean sum of squares	Variance ratio
Blocks	7	42.5729		9.2086		67.7900	
Treatments	11	451.0173	22.250**	78.5245	4.645**	64.8791	2.404*
Linear	1	3298.4000	162.700**	235.2600	13.916**	448.4500	16.614**
Residual	9	35.0022	1.727	65.8744	3.897**	11.1800	0.414
Rest	1	1347.7700		35.6400		164.5900	
Error	77	20.2725		16.9056		26.9919	

TABLE 2

Serial analysis

Source	D. F.	Mean sum of squares	Variance ratio
Blocks	14	43.2493	
Treatments	11	405.6182	11.519**
Linear	1	2941.9700	83.546**
Residual	9	54.7411	1.555
Rest	1	1027.1600	
Years	1	18496.0000	
Interaction (Years × treatments)	11	35 2136	1.685
Pooled error	154	20.8990	

* Significant at 5 per cent ** Significant at 1 per cent

TABLE 3

Yield of wheat grain (C. 518) in md. per acre

Treatments	Levels of N	P	K	YEARS 1950-51	1951-52	1952-53	Average of three years (calculated)
A	0	0	0	18.06	11.94	32.11	20.70
B	0	60	40	19.20	11.46	33.58	21.41
C	10	60	40	21.85	11.40	33.07	22.11
D	20	60	40	26.01	11.89	35.54	24.48
E	30	60	40	27.66	10.97	34.06	24.23
F	40	60	40	30.75	12.69	36.39	26.61
G	50	60	40	30.62	19:90	35.41	28.64
H	60	60	40	30.53	13.88	35.77	26.73
I	70	60	40	30.72	13.93	36.52	27.06
J	80	60	40	36.58	17.27	39.71	31.19
K	90	60	40	36.47	15.55	39.19	30.40
L	100	60	40	36.64	13.29	38.84	29.59
S. Em				± 1.37	± 1.25	± 1.58	± 1.04
C. D. at 5 per cent				3.86	3.52	4.45	3.24
'F' test				significant at 1 per cent	significant at 1 per cent	significant at 5 per cent	significant at 1 per cent

TABLE 4

Response curve in md. per acre

Years	Yield equation	Response	Expected response per lb. of nitrogen
1950-51	$Y=21.3987+0.16662x$	Linear	0.16662
1951-52	$Y=11.6141+0.04449x$	Linear	0.04449
1952-53	$Y=33.1172+0.06144x$	Linear	0.06144
Average of 3 years without PK	$Y=22.0423+0.09085x$	Linear	0.09085
with PK	$Y=21.8182+0.09407x$	Linear	0.09407
Difference in average response			0.00322
S. Ed			0.01406
t			0.23 Not significant

Results in table 3 show that the application of nitrogen at all levels has given higher yields than control *i e.* no nitrogen. Application of PK alone has given a slight increase over the control but the difference is small and not significant. In 1950-51, highest yield has been obtained with a dose of 100 lb. nitrogen per acre and that the yields obtained with 80, 90 and 100 lb. nitrogen are equal as the differences between them are very small and not significant. The differences between any one of these three treatments and the rest of the treatments are large and significant. Application of 10 lb. nitrogen per acre has given higher results than controls but the differences are not significant and has given significantly lower yields than the rest of nitrogen treatments. There are very slight differences between the yields obtained with the application of 30, 40, 50, 60 and 70 lb. of nitrogen. During 1951-52, highest yield was obtained with the application of 50 lb. nitrogen, but the differences between 50, 80 and 90 lb. nitrogen are small and not significant. The differences between yields obtained with 50 lb. nitrogen and the rest of doses of nitrogen excepting 80 and 90 lb. nitrogen are significant. Similarly application of 80 lb. nitrogen has given significantly more yield than 100, 40, 30, 20 lb. nitrogen and control. The rest of the treatments do not exhibit great variation.

During 1952-53, highest yield was obtained with 80 lb. nitrogen followed by 90 and 100 lb. All the doses of nitrogen have given higher yields than control. Though various doses of nitrogen have given higher yield than control, the differences in the yield of the control and different doses of nitrogen excepting 80, 90 and 100 lb. of nitrogen are not significant. Application of 80, 90 and 100 lb. of nitrogen have given significantly higher yield than 10, 30 lb. of nitrogen and control. Rest of the treatments do not differ significantly among themselves. In general, the trend with slight modification is nearly the same during the three different years.

As regards the serial analysis, application of 80 and 90 lb. of nitrogen have come out to be the best followed by 100 and 50 lb. of nitrogen. The differences amongst these four doses, however, are not significant. Application of 70, 60, 40, 30 and 20 lb. of nitrogen have shown similar behaviour and that the differences between these doses and the control are significant. Application of 10 lb. of nitrogen has given higher yield than the control, but the difference is not significant. The trend of results in the serial analysis is nearly the same as in individual years.

In general, application of 80 and 90 lb. of nitrogen have come out to be the best followed by 100 and 50 lb. of nitrogen per acre.

Response : Yield dose relation is shown in Fig. 1. The rate of response in each year is shown in table 4. The response in individual years and average of three years is linear (tables 1 and 2) excepting in 1951-52, where linearity although not perfectly established, indications are that the rate of response is linear. Such a behaviour during 1951-52 was due to abnormal climatic conditions *i. e.*, heavy hailstorm which lodged the entire crop and thus the effect of treatments got masked up. It is further seen that the average response of three years in presence of PK is more than without PK. The difference between these two responses are however not significant. Such a finding has also been reported by Thorne (1903), Hudson and Woodcock (1934) and Chandnani (1954). In both the cases the response was linear. Thus the effect of application of nitrogen in increasing yield of wheat is clearly brought out. Such an effect has been reported from several workers in India and outside.

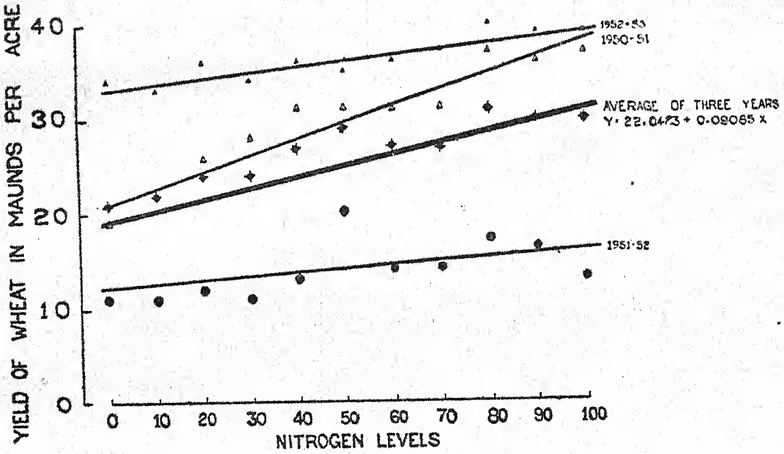

Fig. 1.—Response of nitrogen

The yield of wheat increases with increase in dose of nitrogen. It appears that in this particular variety (C. 518), one could get linear increase in yield even up to a dose of 100 lb. nitrogen per acre. Such a behaviour may be explained due to the fact that the variety C. 518 is known to do very well in high fertility conditions. It may be this character of the variety which may be responsible for the linear response up to 100 lb. of nitrogen per acre.

Since the yield dose relation is adequately represented by a straight line, the rate of response is constant for the range tried. These results, therefore, suggest an application of still higher doses than 100 lb. of nitrogen to work out an optimum dose of application of nitrogen.

From these results, the doses of 50, 80 and 90 lb. of nitrogen may be taken as optimum, though these doses are not exactly optimum doses as indicated, but can be taken near about them.

Economics : Method of working economics has already been described in the foregoing pages. The results obtained are given in table 5.

TABLE 5

Economics in presence and absence of PK in rupees per acre

Nitrogen dose (lb./acre)	Response of nitrogen in maunds per acre		Net profits (+) Net loss (−) in rupees per acre	
	In presence of PK	In absence of PK	In presence of PK	In absence of PK
10	1.4	0.7	−40.7	+ 0.4
20	3.8	3.1	− 6.5	+31 6
30	3.5	2.8	−22.0	+19.1
40	5.9	5.2	+10.6	+51.7
50	7.9	7.2	+40.2	+84.3
60	6.0	5.3	− 2.6	+38.5
70	6.4	5.7	− 7.7	+31.4
80	10.5	9.8	+53.9	+95.0
90	9.7	9.0	+30.1	+71.2
100	8.9	8.2	− 0.9	+50.2

It will be seen from the above that, in general, though the addition of PK increases the yield of grain, the increase thus obtained does not compensate the expenditure involved in the use of PK excepting in case of 40, 50, 80 and 90 lb. N per acre.

The use of nitrogen alone has proved to be economical irrespective of the dose. The net return realised with nitrogen alone is more than in presence of PK. As regards economics, the use of PK is not warranted. Fig. 2 shows the curve of economics.

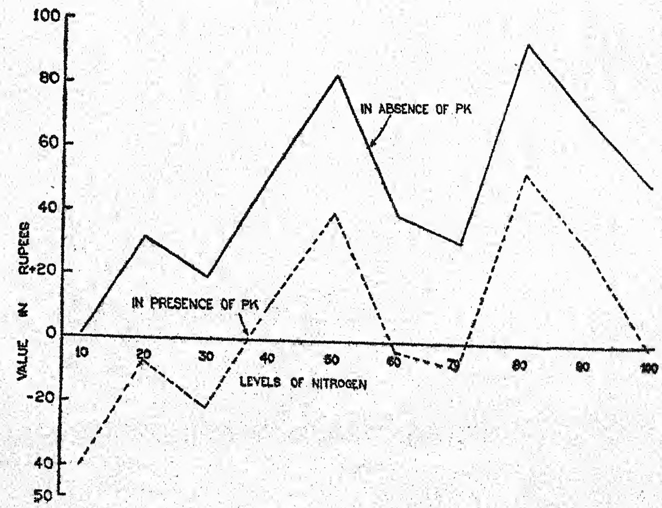

Fig. 2.—Net profit or loss

These results indicate that the application of nitrogen at the level of 80, 50 and 90 lb. per acre have come out to be the best as regards net profits both in presence and absence of PK.

Quality of grain: Composite samples of wheat grain were collected each year from different treatments and got analysed in the division of Soil Science and Agricultural Chemistry for their nitrogen content. The results of three years are given below:

TABLE 6

Nitrogen in wheat grain
(Per cent on ovan-dry basis)

Doses of nitrogen in lb. per acre	Nitrogen			Average of 3 years (calculated)
	1950-51	1951-52	1952-53	
A. No nitrogen	1.44	1.92	1.85	1.74
B. 20	1.47	2.17	1.75	1.80
C. 40	1.50	2.00	1.80	1.77
D. 60	1.61	2.12	2.04	1.92
E. 80	1.62	2.57	2.13	2.11
F. 100	1.84	2.09	2.04	1.99
Average	1.58	2.14	1.93	
'F' test				Sig. at 5%
S. E.				±0.075
C. D. at 5%				0.24

The effect of different years was also studied on the nitrogen content of grain with the following results:

Year	*Nitrogen* (%)
Y_1—1950-51	1.58
Y_2—1951-52	2.14
Y_3—1952-53	1.93
'F' test	Significant at 1%
S. E.	±0.053
C. D. at 5%	0.17

The results in table 6 indicate that the nitrogen content of the grain increases with the increase in the application of nitrogen. The average effect of 3 years was statistically analysed and it was found that there was an increase in nitrogen content of the grain with the increase in nitrogen application. The application of 80 lb. N gave the highest nitrogen content in the grain and the differences between 80, 40, 20 lb. of N and no nitrogen were significant. The differences between 80, 100 and 60 lb. of N were, however, slight and not significant.

These results have clearly brought out that the application of nitrogen to wheat results in the increase of quantity and quality and that the application of nitrogen at 80 lb. nitrogen per acre gives the best quality grain. Similar findings i.e. increase innitrogen content of the grain due to application of nitrogen were reported by Murphy (1930), Doneen (1934), Torsell (1940), Walster (1946) and Chandnani (1954).

It is also further seen that the nitrogen content of the grain is affected by the season i.e. years. Highest nitrogen content was obtained in 1951-52 when the season was abnormal and yields of grain were low followed by 1952-53 and 1950-51.

SUMMARY

An experiment on response curve of nitrogen with wheat C.518 was started in 1950-51 and closed in 1952-53. This included study of 10 doses of nitrogen ranging from zero to 100 lb. N per acre. 60 lb. P_2O_5 and 40 lb. K_2O per acre were applied as a basal dressing. The results obtained with regard to yield, response, economics and quality have been described and discussed in the foregoing pages. As a result of 3 years' work, following conclusions have been drawn.

1. Wheat responds to the application of nitrogen.

2. There is increase in yield with increase in application of nitrogen.

3. The increase from the application of 10 lb. to 100 lb. nitrogen per acre is linear.

4. Response in maund per lb. of nitrogen varies from year to year. It was 0.17 maunds per lb. of nitrogen in 1950-51, 0.04 maunds per lb. of nitrogen in 1951-52 and 0.06 maunds per lb. of nitrogen in 1952-53. The response in each year was linear.

5. Response was comparatively more in the presense of PK than otherwise.

6. As the yield dose relation is linear, it suggests that higher doses than 100 lb. of N per acre would be necessary to fix up optimum dose.

7. These results however reveal that in case of C 518, a dose of 50, 80 or 90 lb. N per acre would give the best performance.

8. Studies on economics reveal that the net returns are more when nitrogen is used alone. The highest returns are obtained with 80 lb. nitrogen followed by 50 and 90 lb. nitrogen per acre.

9. Application of nitrogen affects both quantity and quality. The nitrogen content of wheat grain increases with increase in the application of nitrogen. Application of 80 lb. nitrogen gives the highest increase in nitrogen content of the grain.

10. The nitrogen content of the grain is affected by season and response. Higher the response per lb. of nitrogen, less the increase in the nitrogen content of grain.

11. Taking all factors together, application of 80 lb. nitrogen per acre has shown the best results.

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The Climate of The Bombay State

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There are five principal factors of soil formation, *viz.*, 1. parent material, 2. climate, 3. vegetation, 4. relief and 5. time. Climate, aided by vegetation which it fosters, acts upon the parent material. The action of these two factors is conditioned by local relief or topography. The length of time during which these factors are operative further influences the character of the ultimate product. The factors are thus interdependent, each modifying the influence of the other. Climate, however, is the most dominant factor. It is responsible to a very large extent in influencing the nature of a soil. While the differences due to parent material and relief are more or less local, those due to climate cover large areas. At first the parent material, on weathering, produces a distinct kind of soil, but as time goes on, the distinction between soils derived from different parent materials situated in a climatic zone gradually disappears. Each climate together with its vegetation and other biological activities that it promotes, imparts its own special characteristics to the soil, no matter what the original parent material may have been. With the lapse of time, the influence of the parent material is completely obliterated with the result that all soils in any given region tend to become alike. Though young soils may vary greatly, old or mature soils assume a uniform character.

Climate influences soil formation both directly and indirectly. Directly it affects the weathering of rocks and the transportation and redeposition of the products of weathering. One of its most important effects is its influence on the movement of water in the soil through percolation, leaching, runoff, etc. It is largely this direct effect of climate which is responsible for the development of soil. Many of the products so formed are true soils, but some of them are the parent materials from which new soils are now developing. Indirectly it influences soil formation through the activities of plant and animal life. The nature and type of vegetation which is determined by climatic factors like temperature and rainfall modify, in turn, the effects of these factors particularly rainfall. Organisms, both big and small, considerably influence the action of climate. Though they play a role of secondary importance, their total influence is very great. Relief also plays an important part in controlling the effect of climate in soil formation by influencing the air-water regime in the soil.

An attempt has been made in this paper to give an account of the climatic conditions prevalent in the Bombay State.

Climate may be defined as a "complex of meteorological conditions which exists in any given area and imparts an individuality to the landscape of that area." Among the numerous meteorological elements, those that take part in soil formation are precipitation, temperature, relative humidity and evaporation. In considering the climate of the Bombay State, a study of these four elements has been presented. Though wind is an important meteorological element, it has not been considered separately in this paper.

The climate of the Bombay State is a part of the climatic pattern of India. Though it shares the wider climatic characteristics of the country, it has several distinctive features of its own.

PRECIPITATION*

The rainfall of the Bombay State is derived chiefly from the south-west monsoon, between June and October. In the eastern tracts of the Deccan and Karnatak this supply is greatly supplemented by the fall of the north-east monsoon which follows the close of the south-west monsoon. The south-west monsoon touches North Kanara, the southern-most district first and works its way up towards Gujarat. As it advances, the amount of precipitation for which it is responsible decreases from south to north along the coast. Thus, Bhatkal at the extreme south on the coast of North Kanara receives an annual rainfall of 151 inches ; Ratnagiri about two hundred miles north receives 102 inches, Alibag another 100 miles in the same direction has 87 inches, while Umbergaon in the north of the Thana district receives only 63 inches.

The high range of the Western Ghats, in as much as it arrests the surcharged clouds, receives more rainfall than the coast-line over which the clouds come. Thus Ratnagiri, Guhagar, Alibag and Mahim being on the coast-line receive 102 inches, 99 inches, 87 inches and 65 inches of rainfall respectively, while Devrukh, Chiplun, Lonavla and Igatpuri being on or near the Ghats in the same latitude as the above places receive 146 inches, 141 inches, 170 inches and 132 inches respectively. It will thus be seen that the western face of the Western Ghats arrests much of the rain. The line of the Western Ghats which runs nearly parallel to the coast, and the ramifications of the Ghats on the western side, cause considerable variation in the amount of rain received in the Deccan and Karnatak districts, as the current of the south-west monsoon has to pass across the Ghats. The Deccan districts have a slight slope to the east, away from the Western Ghats and most of the rain which crosses the Ghats falls in the uplands. The rainfall map (Fig. 1) shows how the rainfall decreases eastward and to a less extent westward from the summit of the Ghats. Khandesh and especially East Khandesh receives a little additional rainfall from the east, from wind currents originating in the Bay of Bengal.

By about September the force of the south-west monsoon decreases and soon after, a series of storms, arriving apparently from the north-east supplies rain to Ahmednagar, Sholapur, Bijapur and the eastern parts of Dharwar and Belgaum districts. Sometimes these storms spread further west, but as a whole they form perhaps the most doubtful factor in the annual rainfall.

REGIONAL DISTRIBUTION OF RAINFALL

Fig. 1 shows the regional distribution of rainfall in the Bombay State. It can be divided into the following tracts on the basis of the distribution of rainfall :—

(1) *The heavy rainfall tract* :—This tract comprises the Konkan and a narrow strip of about 15 to 20 miles on the crest of the Western Ghats from North Kanara to the Dangs. This tract receives 60 inches or more of rain annually, the stations which are actually on the crest of the Western Ghats recording very large quantities, from 250 to 300 inches per annum. As has already been noted, the rainfall in this tract decreases as one proceeds north from 151 inches at Bhatkal the southern most point, to 63 at Umbergaon in the north of Thana.

(2) *The Mawal or Mallad tract* :—This tract receives from 30 to 60 inches of rain per annum. It lies immediately to the east of the tract described above, and usually has an elevation above the sea of two thousand feet or more. It embraces the western portions of the districts of Nasik, Poona, Satara North, Satara South, the central portion of Kolhapur and the Akola taluka of Ahmednagar districts in the Deccan, and of Belgaum and Dharwar districts in the Karnatak. The distribution of the rain is very similar to that of the heavy rainfall tract already dealt with.

*Taken from Statistical Atlas of the Bombay Presidency, 3rd edi., 1925.

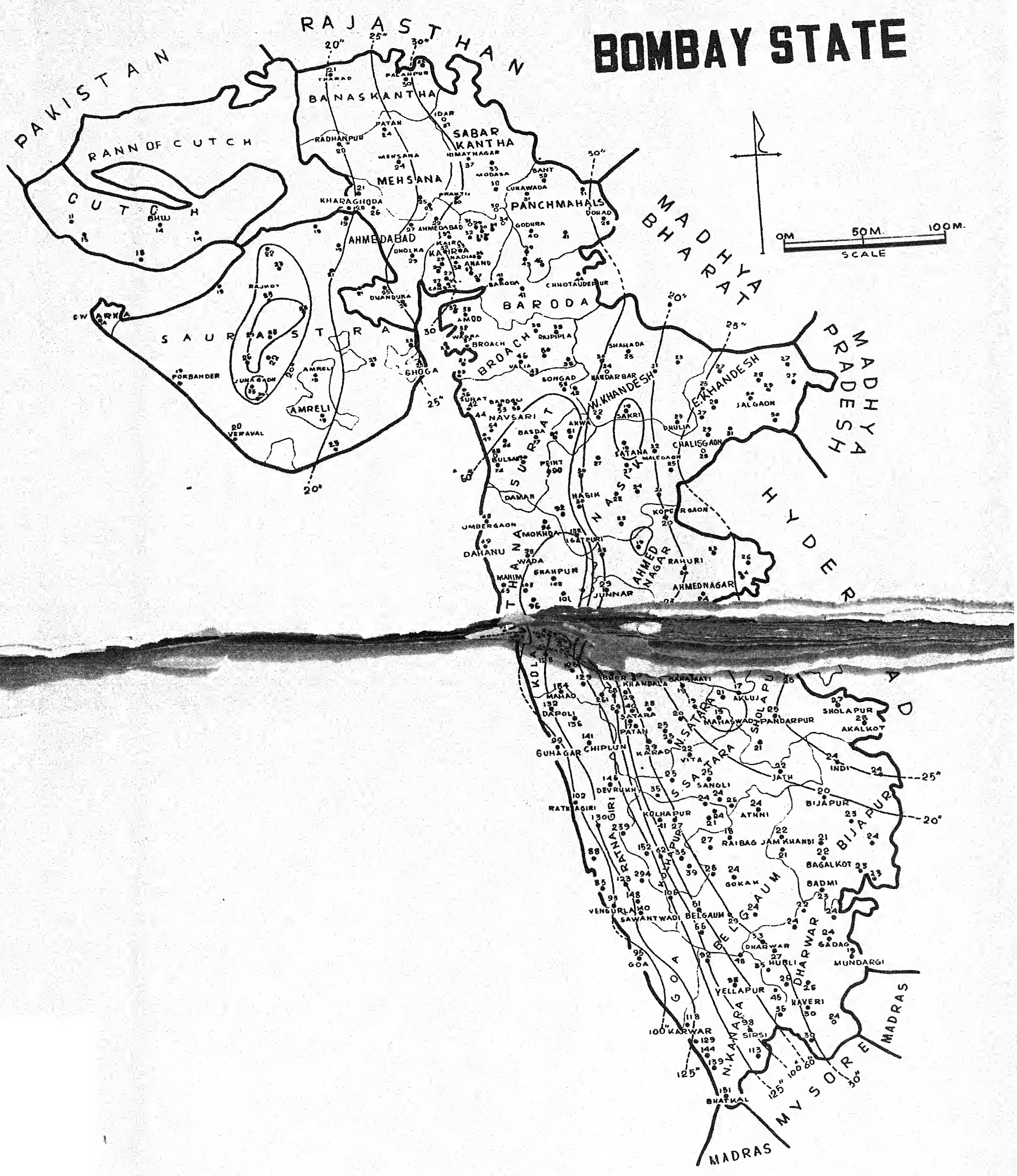

Fig. 1.—Regional distribution of rainfall

(3) *The Desh tract* :—To the east of the *Mallad* or *Mawal* tract lies what is usually called the *Desh*. In this region the land becomes much more level and the rainfall varies from 20 to 30 inches. The eastern tract which receives about 20 inches of rain is chronically liable to drought and famine. In these eastern parts, moreover, the chief dependence is on the rain in August and September.

(4) *The Khandesh tract* :—The Khandesh tract consists almost entirely of the valley of the river Tapti, and the surrounding country. It receives from 20 to 30 inches of rain per annum and has rainfall features of its own. At this latitude the Western Ghats are no longer the formidable barrier that they are further south but on the other hand the Satpura range, which forms the northern boundary of Khandesh, intercepts a great deal of the rain which is passing north in the south-west monsoon current. At the same time the country is open to the east and a certain amount of rain from the Bay of Bengal current of the monsoon reaches Khandesh. As a result of these features, the rainfall of Khandesh though only from 20 to 30 inches annually in amount, is much more certain than in the *Desh* country further south.

(5) *Gujarat tract* :—The rainfall in Gujarat which, in the extreme south is from 50 to 60 inches annually, soon becomes not more than 42 inches at Surat and less and less from that point as one goes north. The western portions of the extreme northern district of Banaskantha, and of Mehsana and Ahmedabad districts adjoining the Cutch desert, usually receive less than 20 inches of rainfall. It is, moreover, entirely a rainfall of the south-west monsoon and it stops as a rule in September. After this time no appreciable amount of rain falls until the following June.

The average rainfall of the Bombay State is computed at 46.56 inches distributed in the four geographical regions as under :

	Average rainfall (inch)	Average number of rainy days
Bombay State	46.56	53.1
Gujarat	32.54	37·9
Deccan	38.89	51.7
Karnatak	30.47	51.4
Konkan	112.84	95.8

SEASONAL DISTRIBUTION OF RAINFALL

The seasonal distribution of rainfall for each district is given in Table 1 and is shown for a few important stations in Fig. 2. Unlike temperate and tropical regions where it rains for a major part of the year, the rainfall in the Bombay State is concentrated in about four to five months of the year when the monsoon is active. The land remains practically dry during the rest of the period. The whole of the rainfall is precipitated, especially in the low rainfall regions, in a relatively short period. The average number of rainy days during the year (Table 1) shows a variation from 26 days in Amreli district to 103 days in North Kanara district. It may be said in general that places having an assured rainfall have a larger number of rainy days. Places in receipt of rains from both the monsoons have also a greater number of rainy days. The short season during which the rainfall is received is quite in contrast to the frequency of rainfall in temperate and tropical countries where the rainfall is distributed over a much longer period (Table 2).

INTENSITY OF RAINFALL

Another characteristic feature of the rainfall of the Bombay State, in common with the rest of India and other tropical countries, is its high intensity or "heaviness." The

TABLE 1

Annual and seasonal distribution of rainfall

District	Number of recording stations	Average rainfall in inches				Average number of rainy days				Intensity of rainfall
		Annual	Seasonal			Annual	Seasonal			
			January to May	June to September	October to December		January to May	June to September	October to December	
1	2	3	4	5	6	7	8	9	10	11
Banaskantha	3	27.39	0.76	25.97	0.66	29.8	1.6	27.0	1.2	0.8
Sabarkantha	5	32.12	0.67	30.85	0.60	37.8	1.4	35.3	1.1	0.8
Mehsana	4	23.36	0.51	22.30	0.55	29.0	1.2	26.7	1.1	0.8
Amreli	4	18.91	0.46	17.05	1.40	26.2	0.9	23.2	2.1	0.7
Ahmedabad	10	24.67	0.57	23.35	0.75	31.4	1.1	28.9	1.4	0.7
Kaira	18	31.53	0.51	30.17	0.85	36.6	1.0	34.1	1.5	0.8
Baroda	4	37.01	0.44	34.79	1.78	41.8	1.1	38.3	2.4	0.8
Panch Mahals	9	36.83	0.68	34.84	1.31	43.1	1.3	39.7	2.1	0.8
Broach	13	36.35	0.36	33.92	2.07	42.9	0.9	39.7	2.3	0.8
Surat	15	57.26	0.46	54.50	2.30	60.4	1.0	56.6	2.8	0.9
W. Khandesh	9	25.47	0.78	22.59	2.10	41.5	1.6	36.8	3.1	0.6
E. Khandesh	13	28.15	1.14	24.64	2.37	43.6	2.5	37.5	3.6	0.6
Dangs	2	74.95	0.87	70.29	3.79	79.3	1.7	72.6	5.0	0.9
Nasik	14	41.68	1.24	36.91	3.53	52.8	2.2	45.4	5.2	0.7
Ahmednagar	13	22.64	1.48	17.38	3.78	35.9	2.9	27.4	5.6	0.6
Poona	16	36.57	1.57	30.64	4.36	50.1	3.2	40.3	6.6	0.7
Satara North	13	31.73	2.21	24.48	5.04	50.0	4.4	38.0	7.6	0.6
Satara South	10	26.52	3.07	18.24	5.21	49.3	5.6	35.6	8.1	0.5
Sholapur	9	23.85	1.80	17.45	4.60	38.0	4.0	27.2	6.8	0.6
Kolhapur	8	77.34	2.93	67.61	6.80	76.6	5.4	61.9	9.3	1.0
Belgaum	11	41.78	4.37	30.49	6.92	62.6	8.0	44.2	10.4	0.6
Bijapur	12	22.43	2.86	14.36	5.21	38.0	5.9	24.4	7.7	0.6
Dharwar	14	27.22	4.32	16.40	6.50	53.6	7.8	36.0	9.8	0.5
Thana	11	87.99	0.83	83.46	3.70	82.2	1.2	76.5	4.5	1.0
Kolaba	9	121.70	0.98	115.65	5.07	95.4	1.5	87.7	6.2	1.2
Ratnagiri	15	134.83	1.99	126.23	6.61	102.6	2.5	91.4	8.7	1 3
N. Kanara	11	106.84	4.36	94.29	8.19	103.2	6.5	85.0	11.7	1.0

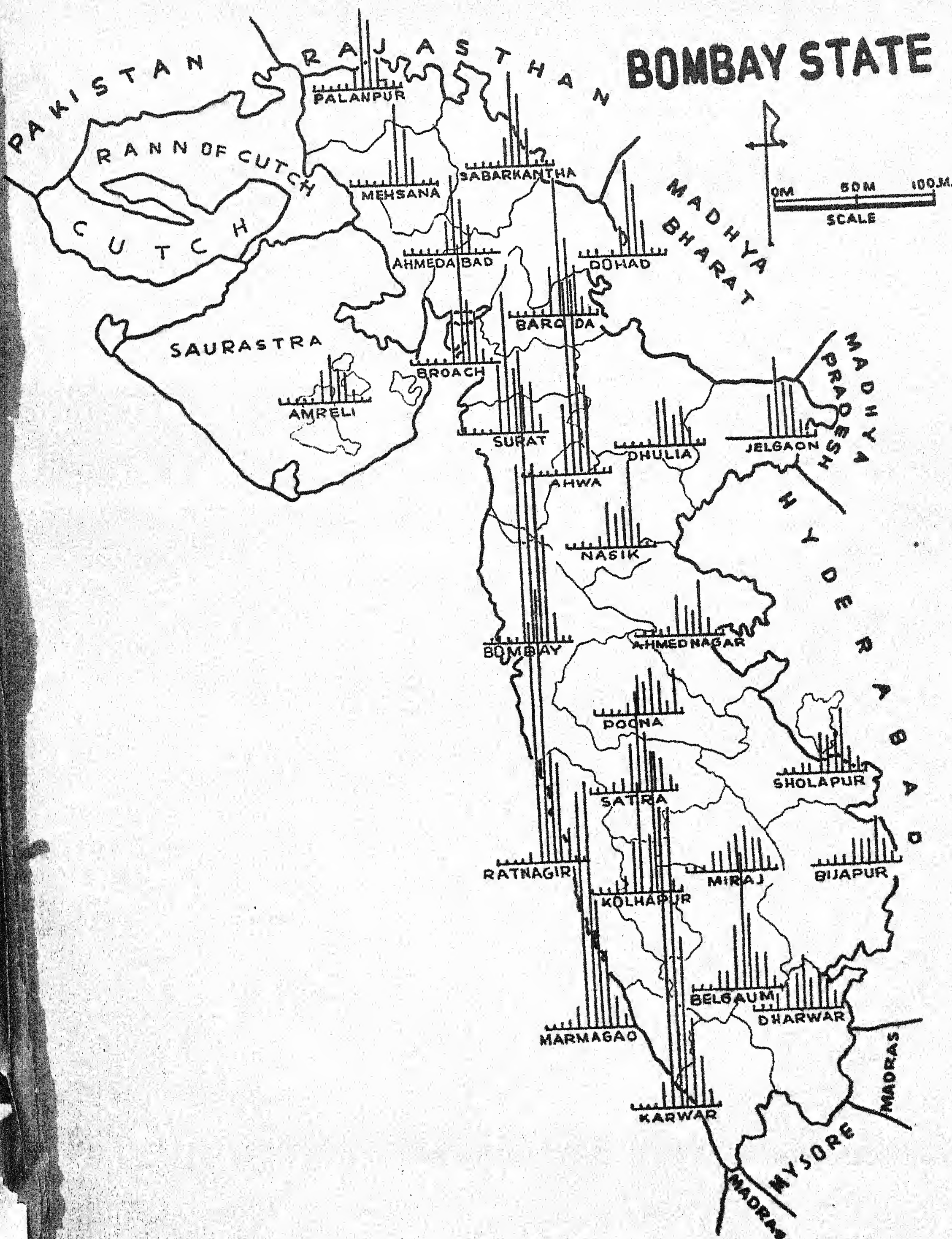

Fig. 2.—Seasonal distribution of rainfall

figures in column 11 in Table 1, obtained by dividing rainfall by the number of rainy days, gives an idea of the intensity of rainfall.

The average rainfall per day varies from 0.5 inch to 1.3 inches. This is far in excess of the intensity of rainfall in temperate countries like the British Isles as can be seen from Table 2.

TABLE 2

Rainfall in some of the temperate and tropical countries

	Average annual rainfall	Average number of rainy days	Intensity of rainfall
	(inch)		
1. India	42.3	51	0.83
2. Ceylon	79.9	157	0.51
3. Burma	121.3	142	0.85
4. Scotland	50.32	217	0.23
5. Ireland	43.30	220	0.19
6. England & Wales	35.23	188	0.18

As a result of the high intensity of rainfall, a large quantity of rain water flows off the surface of the land as the heavy downpour does not allow time for the infiltration of water into the ground. Experiments carried out at Sholapur (Kanitkar, 1944) show that nearly half the total rainfall in a year is so intense as to cause surface run-off. The effective rainfall or the rain water that penetrates into the soil mass and takes part in the processes of soil formation, plant nutrition, etc., is thus reduced to nearly half the annual precipitation. In addition to the loss of rain water, considerable quantities of soil, especially the finer particles, are lost due to erosion. It is computed that on an average, about 30 to 40 tons of soil are lost every year from an acre of land in the Deccan and Karnatak. The loss of soil due to erosion in the Konkan is likely to be still greater on account of the higher intensity of rainfall in this region. The intensity of rainfall in Gujarat is of an intermediate order. Though no actual figures of rain water and silt lost due to run-off in Gujarat are available, it is likely that on account of the flat nature of the land and the medium intensity of rainfall the losses must not be very great.

TEMPERATURE*

Temperature is as important a factor in soil formation as rainfall. It influences the rate of weathering, chemical and biological reactions taking place in the soil, the nature of the colloidal clay, soil profile development, the rate of decomposition of organic matter, etc. It is computed that in tropical regions, weathering proceeds three times faster than in temperate zones, and nine times faster than in the arctic (Jenny, 1941).

In Bombay State, temperature shows considerable seasonal, diurnal and regional variations. Table 3 gives the mean maximum, mean minimum and mean temperatures in different parts of the State. February witnesses a general rise in maximum temperature throughout the State except Konkan. It is in March, however, that the hot-weather begins. The temperature continues to rise in April and the highest maximum temperature is usually reached in May. With the onset of the monsoon in June there is a drop in

*Taken from Statistical Atlas of Bombay State, 4th edi., 1950.

TABLE 3

Maximum, minimum and mean temperatures

		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Gujarat	Mean maximum	91.9	96.2	102.1	108.7	110.3	105.4	97.6	93.6	97.3	99.7	96.2	91.4	
	Mean minimum	44.1	47.0	54.5	64.2	72.2	74.4	73.6	73.2	70.5	61.3	53.7	47.4	
	Mean	69.3	72.5	80.0	87.3	91.1	89.2	83.8	82.1	82.5	82.2	76.1	70.7	80.6
Deesa	Mean maximum	90.8	95.4	104.5	110.5	113.6	110.3	102.5	96.3	101.0	102.2	97.9	91.7	
	Mean minimum	40.1	43.4	51.7	62.2	70.4	74.9	73.7	72.8	69.2	58.4	50.4	44.1	
	Mean	67.2	70.4	79.4	87.5	92.3	91.7	85.7	82.8	83.8	82.3	75.2	69.1	80.6
Ahmedabad	Mean maximum	91.6	96.5	105.0	110.2	112.4	108.4	100.3	95.2	99.3	100.9	97.6	91.6	
	Mean minimum	49.7	51.0	58.5	67.9	74.3	74.9	74.5	74.1	72.8	67.8	59.5	52.7	
	Mean	71.2	73.9	82.3	89.1	93.0	91.4	85.8	83.3	84.3	84.9	79.1	73.0	82.6
Dohad	Mean maximum	90.7	94.2	102.3	106.1	108.6	103.4	95.4	91.8	94.7	97.3	94.0	89.7	
	Mean minimum	41.9	46.3	53.6	65.0	74.0	73.0	71.8	71.6	68.6	59.1	51.6	46.2	
	Mean	68.1	71.6	79.1	87.7	90.9	87.9	81.3	79.8	79.5	79.9	73.7	68.7	79.1
Baroda	Mean maximum	93.5	97.0	103.9	109.1	110.4	104.6	96.8	94.3	96.8	100.0	95.8	91.6	
	Mean minimum	38.9	44.4	50.0	58.9	68.9	74.9	74.0	73.9	69.9	57.9	49.4	43.4	
	Mean	67.9	72.1	78.0	85.9	91.1	88.7	83.7	83.1	82.6	80.7	74.4	69.3	79.8
Surat	Mean maximum	93.3	98.2	94.9	107.7	106.7	100.5	93.0	90.4	94.8	98.5	96.1	92.4	
	Mean minimum	50.2	50.1	59.0	67.2	73.5	74.5	74.1	74.0	72.3	63.3	57.9	52.6	
	Mean	72.3	74.7	81.5	86.4	88.1	86.3	82.5	81.7	82.3	83.1	78.4	73.7	80.9

TABLE 3 (CONTD.)

		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Deccan	Mean maximum	91.5	96.5	102.8	106.9	108.5	101.4	92.8	91.2	93.2	94.2	91.3	88.7	
	Mean minimum	47.0	48.5	55.2	63.3	69.1	69.7	69.3	67.4	65.1	58.4	50.3	45.7	
	Mean	70.7	74.1	80.8	86.8	89.0	83.7	79.1	78.4	78.4	78.5	73.2	69.4	78.5
Jalgaon	Mean maximum	94.3	98.3	105.0	111.7	114.5	106.0	97.5	95.3	95.7	98.0	94.0	89.8	
	Mean minimum	44.7	46.7	54.3	63.5	74.7	72.7	72.0	69.7	66.7	56.9	47.4	40.6	
	Mean	71.2	75.1	81.8	90.1	94.5	88.3	81.6	81.5	81.6	80.0	73.7	68.7	80.6
Malegaon	Mean maximum	92.1	97.2	103.9	107.9	109.9	104.6	95·2	92.7	94.1	95.6	92.5	89.6	
	Mean minimum	43.3	43.6	52.2	62.1	68.9	70.6	70.5	68.3	65.4	56.9	48.7	43.8	
	Mean	69.3	72.3	80.1	87.1	90.1	85.7	80.9	79.6	79.5	78.8	72.7	68.7	78.7
Ahmednagar	Mean maximum	89.3	94.5	100.8	105.0	106.7	101.7	91.1	90.7	91.7	92.7	89.6	87.0	
	Mean minimum	45.2	46.9	53.4	61.0	65.3	67.7	67.1	64.2	62.4	56.8	49.0	44.5	
	Mean	68.9	72.2	79.3	85.1	87.0	82.1	77.9	77.1	77.0	77.1	71.7	68.0	76.9
Poona	Mean maximum	91.0	96.1	102.4	105.8	105.7	98.7	88.6	86.5	93.0	93.3	90.9	88.8	
	Mean minimum	46.7	47.4	53.8	61.1	66.4	69.0	68.5	67.0	64.4	57.7	49.9	46.1	
	Mean	69.7	72.8	79.3	84.6	85.6	81.5	77.1	76.1	76.7	77.9	72.5	68.9	76.9
Sholapur	Mean maximum	92.0	97.8	104.1	107.7	109.4	104.2	96.2	94.4	94.3	94.4	91.9	89.2	
	Mean minimum	52.3	55.0	61.3	68.5	71.1	69.8	69.2	68.3	67.5	61.4	54.0	50.4	
	Mean	73.3	77.6	84.2	89.4	90.9	84.5	80.7	79.9	79.9	79.7	75.1	72.0	80.6

Miraj	Mean maximum	90.3	95.0	100.6	103.5	104.7	93.3	88.1	87.9	90.5	91.5	89.3	87.8	
	Mean minimum	50.1	51.4	56.2	63.8	68.1	68.6	68.6	67.3	64.1	61.0	52.7	49.2	
	Mean	71.9	74.7	80.1	84.6	85.9	80.1	76.3	76.1	76.1	77.6	73.9	70.5	77.3
Karnatak	Mean maximum	89.9	94.5	101.7	102.9	103.5	96.3	87.8	87.4	89.4	90.7	88.1	87.1	
	Mean minimum	53.7	56.3	61.1	65.6	67.3	67.3	67.2	66.3	64.7	61.7	55.2	52.4	
	Mean	72.5	76.4	81.4	84.9	84.8	78.8	75.7	75.5	75.9	77.0	73.7	71.3	77.3
Bijapur	Mean maximum	90.7	95.6	101.2	104.7	106.1	100.8	92.8	91.9	92.3	92.6	89.6	87.8	
	Mean minimum	53.1	56.2	62.8	68.0	69.3	68.4	68.2	67.2	66.4	61.5	53.6	50.1	
	Mean	73.2	77.5	83.6	87.6	88.1	82.1	78.7	78.4	78.6	78.7	74.2	71.4	79.3
Belgaum	Mean maximum	88.1	93.1	97.9	101.2	100.2	91.7	81.6	81.0	84.9	87.7	86.0	85.5	
	Mean minimum	51.9	52.7	57.9	62.1	64.2	65.1	65.3	64.4	61.9	59.6	54.5	52.2	
	Mean	70.8	73.8	78.6	81.5	80.8	74.9	71.8	71.6	72 9	74.4	72.1	70.2	74.4
Gadag	Mean maximum	90.9	94.8	106.0	102.9	104.4	96.6	89.2	89.4	91.2	92.0	88.7	88.2	
	Mean minimum	56.1	60.2	62.6	66.7	68.5	68.4	68.1	67.5	65.9	64.1	57.6	54.9	
	Mean	73.4	77.8	82.1	85.6	85.5	79.5	76.5	76.6	77.1	77.9	74.9	72.3	78.3
Konkan	Mean maximum	90.6	90.1	92.4	92.0	92.3	90.9	86.9	86.0	86.7	94.1	93.2	91.7	
	Mean minimum	61,5	62.1	66.9	72.7	76.0	73.2	73.3	73.4	72.8	70.7	66.7	63·7	
	Mean	75.7	75.7	79.0	82.6	84.7	82 1	80.2	79.8	79.7	81.3	80.4	77.5	79.9
Bombay	Mean maximum	88.3	88.8	91.9	92.5	93.2	92.2	88.3	86.8	88.1	92.6	91.8	89.5	
	Mean minimum	62.2	62.5	68.2	73.9	77.6	75.0	74.7	74.7	74.4	73.2	69.5	65.1	
	Mean	74.9	75.3	79.1	82.6	85.3	83.5	81.1	80.5	80.6	82.2	80.9	77.7	80.3
Alibag	Mean maximum	89.0	90.0	94.9	92.4	92.8	91.3	87.1	87.5	87.7	95.2	93.9	92.4	
	Mean minimum	56.9	58.6	63.6	69.8	74.8	73.6	74.1	74.3	72.8	69.9	64.1	60.5	
	Mean	73.1	73.7	77.4	81.5	84.0	82.8	81.0	80.5	80.3	81.5	79.1	75.2	79.2
Ratnagiri	Mean maximum	93.9	93.0	93.2	93.0	92.8	91.5	86.9	85.5	86.7	95.6	95.4	93.9	
	Mean minimum	61.4	61.3	66.2	72.6	75.7	72.6	72.6	72.8	72.2	69.6	64.8	62.6	
	Mean	76.9	76.5	79.6	82.9	85.1	81.8	79.8	79.5	79.3	81.3	80.9	78.3	80.1
Marmagao	Mean maximum	91.4	88.9	89.6	90.1	90.4	88.8	85.4	84.2	84.6	93.1	91.9	91.9	
	Mean minimum	65.7	66.1	69.8	74.6	76.2	71.9	71.9	72.1	71.8	70.4	68.7	66.7	
	Mean	78.1	77.5	79.9	83.3	84.3	80.4	78.9	78.6	78.7	80.3	80.7	78.7	80.0

maximum temperature. The drop in temperature continues till September but shows a slight rise in October after the close of the monsoon. The rise in maximum temperature in October is, however, never as great as in May except in Konkan where October registers the maximum temperature of the year. With the advent of the cold weather in November there is a fall in maximum temperatures throughout the State. The fall continues till January.

The minimum temperature also shows considerable seasonal variation. It begins to rise from January onwards and is highest in the month of May or June. It remains more or less constant at this high level throughout the monsoon months from June to September. From October onwards, it begins to fall and the lowest minimum temperature is usually reached in December in the Deccan and Karnatak and in January in Gujarat and Konkan.

The range of variation in both maximum and minimum temperatures is the least in Konkan and the greatest in Gujarat. Of the other two regions, Karnatak is more equable than the Deccan. On account of its proximity to the sea, Konkan enjoys a more equable climate as far as temperature is concerned. It is the least hot region in summer and the least cold in cold weather. Gujarat, on the other hand, experiences extremes of temperatures. It is the hottest region in summer and the coldest in cold weather. Whereas the mean absolute maximum temperature is 102° F in Konkan, it ranges from 109° F to 118° F in the Deccan and Karnatak and is as high as 122° F in Gujarat. The change of temperature in the course of the year is the greatest in Gujarat which is the driest region of the State and the least in Konkan, the most humid region.

The diurnal variation in temperature much exceeds that experienced in temperate regions. Table 4 shows that it is the least in monsoon from June to September and is the greatest in cold season from December to March. Again Konkan shows the lowest diurnal variation.

TABLE 4

Mean diurnal variaticn in temperature

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Gujarat												
Deesa	32	30	31	30	27	20	13	13	17	27	32	32
Surat	31	31	31	28	21	15	10	11	12	21	28	28
Deccan												
Malegaon	34	35	34	32	29	20	14	14	16	24	30	32
Poona	32	34	34	32	29	17	11	14	15	21	26	29
Sholapur	29	32	32	31	28	23	19	18	18	21	24	27
Karnatak												
Belgaum	25	29	30	30	26	14	9	11	13	18	20	23
Konkan												
Bombay	14	13	11	11	10	8	8	7	8	11	13	14

HUMIDITY

Table 5 gives the mean monthly relative humidity (per cent) for a few stations in the Bombay State. There is a great diversity in regional and seasonal distribution. Gujarat and Deccan are on the whole less humid than the other two regions. Konkan is the most humid region having a mean relative humidity 74. In one and the same region, those stations which are situated to the west are more humid than those situated to the east. There is a considerable seasonal variation which is much greater than the regional variation. The rainy season which lasts from June to September is the most humid period of the year throughout the State. July and August are the most humid months, when the average humidity is about 86 in Konkan, 79 in Karnatak, 74 in the Deccan and 75 in Gujarat. The driest months are March and April, except in Konkan where the driest month is December, when the relative humidity goes down to 35 in Gujarat, 33 in the Deccan, 41 in Karnatak and 61 in Konkan.

TABLE 5

Mean relative humidity

(Average of readings at 8 hr. and 17 hr.*)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Gujarat	40	40	35	36	49	64	76	75	70	52	47	44	52
1. Deesa	33	33	29	30	43	56	71	70	64	40	34	35	45
2. Ahmedabad	35	35	31	32	43	60	73	77	68	48	40	39	48
3. Baroda	45	42	34	33	48	66	80	74	72	61	57	54	55
4. Surat	48	50	46	49	61	72	81	79	76	57	54	48	60
Deccan	42	38	33	33	41	66	75	73	71	55	49	45	52
1. Malegaon	39	37	34	29	38	61	71	69	68	49	46	42	49
2. Ahmednagar	37	31	24	24	31	63	72	71	67	51	45	43	47
3. Poona	47	43	38	37	46	70	80	79	77	63	55	51	57
4. Sholapur	38	31	27	29	35	61	68	67	65	51	43	41	46
5. Miraj	47	44	41	47	56	74	81	80	74	60	53	46	59
Karnatak	46	42	41	49	54	74	79	79	75	63	52	49	59
1. Bijapur	44	39	36	39	42	63	70	68	67	55	48	47	52
2. Belgaum	47	44	44	56	65	84	91	91	86	70	54	49	65
3. Gadag	47	42	43	51	56	74	76	77	72	63	53	50	59
Konkan	63	66	69	72	72	82	86	86	84	79	66	61	74
1. Bombay	67	67	68	71	72	80	85	83	83	77	69	66	74
2. Ratnagiri	59	62	68	71	70	82	87	86	83	75	60	56	71
3. Marmagao	64	69	71	73	74	85	87	88	86	85	67	61	75

*From data supplied by Director of Agricultural Meteorology, Poona.

TABLE 6

Mean monthly evaporation

(Expressed in inches)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual evaporation	Annual rainfall	EP ratio
Gujarat															
Deesa	9.18	9.35	14.97	19.53	22.75	18.99	10.23	6.70	7.38	10.20	10.95	8.93	149.16	24.70	6.0
Ahmedabad	9.30	7.84	12.09	14.40	16.22	12.15	6.63	5.05	5.79	8.31	9.09	8.80	115.67	28.83	4.0
Viramgam	8.46	11.15	14.10	14.67	16.21	12.62	9.87	7.40	10.57	12.68	12.96	10.22	140.91	25.89	5.4
Surat	10.57	12.41	15.86	16.04	16.72	13.13	6.34	7.57	6.82	10.22	12.11	12.52	140.31	41.67	3.3
Deccan															
Ahmednagar	10.60	11.26	17.76	21.39	17.63	8.58	6.67	6.42	5.58	6.17	9.54	8.06	129.66	22.33	5.8
Poona	8.49	8.32	12.71	17.73	14.23	8.82	5.39	4.46	4.50	5.67	7.35	6.82	104.49	27.11	3.8
Sholapur	16.06	16.97	24.15	24.93	20.93	12.30	9.24	8.43	6.54	10.01	12.60	12.68	174.84	28.45	6.1
Jalgaon	9.16	10.51	15.16	16.92	17.37	11.12	4.80	6.45	5.12	10.79	8.62	7.97	123.99	29.21	4.2
Niphad	9.35	11.62	15.34	16.37	17.98	14.33	5.99	6.70	6.48	8.81	9.21	8.11	130.31	26.66	4.9
Karnatak															
Belgaum	9.55	9.24	15.66	11.70	9.39	5.79	2.85	2.45	2.67	5.12	8.13	9.39	91.94	50.13	1.8
Dharwar	10.44	12.73	15.51	13.75	12.44	7.37	5.39	5.15	4.64	5.99	7.95	9.62	110.98	28.78	3.8
Konkan															
Bombay	7.35	7.59	8.43	8.46	8.26	6.87	6.54	5.52	3.87	5.52	6.96	7.35	82.72	70.63	1.2
Karjat	7.05	7.42	10.22	9.76	8.56	4.54	2.11	2.22	1.81	3.63	5.79	6.34	69.45	129.59	0.5
Marmagao	3.72	3.47	5.74	7.41	7.71	3.60	3.29	2.60	1.56	1.71	3.45	4.93	49.19	94.95	0.5

EVAPORATION

Evaporation has a very important bearing on the processes of soil formation. It is the resultant of a number of meteorological factors and hence gives a very good idea of the nature of climate of a given place or region.

Measurements of evaporation from free water surface in this country were not recorded till very recently. Hence no data giving direct evaporation measurements are available. Raman and Satakopan (1935) have calculated evaporation from other meteorological factors like temperature, wind, humidity, etc., which have been recorded for a number of stations in this country over a long period. In Table 6 are given the figures so calculated for evaporation from free water surface at a few stations in the Bombay State. The Department of Agricultural Meteorology, Poona, has started direct measurement of evaporation from Piche evaporimeter during the last three years. The figures so obtained, after conversion into the U.S.A. standard evaporation from free water surface* are also included in Table 6. Though the number of stations for which the data is available is very limited, it may be concluded in general that considerable evaporation takes place over almost the whole of the Bombay State. It is the greatest in Gujarat and the Deccan where evaporation is more than 100 inches per year, and the lowest in Konkan. It is usually high from March to May or June which is the hottest period of the year. With the advent of the monsoon in June there is a sudden check in the rate of evaporation. As the monsoon retreats, the rate of evaporation increases from October onwards and remains more or less steady upto February.

This high rate of evaporation is in marked contrast to that in temperate regions. The annual average evaporation from free water surface recorded at a few stations in England varies from 15 to 19 inches (Table 7). The annual evaporation in temperate regions is usually less than the annual rainfall except in years of drought.

TABLE 7

Evaporation in England **

	Annual average evaporation	Annual average rainfall	EP ratio
	(inch)	(inch)	
Otterbourne	19.71	30.7	0.64
Ormsby St. Michael	17.26	25.3†	0.68
Bartley	17.19	34.1‡	0.50
Southport	15.82	32.0	0.49
Ardsley	17.59	25.4	0.69
Lower Laithe	15.10	—	—
Harrogate	19.53	32.8§	0.59

**Taken from British Rainfall, 1950.
†Average for the county.
‡For 1950.
§Average for 12 Stations.

*The figures were kindly supplied by the Director of Agricultural Meteorology, Poona.

EVAPORATION—PRECIPITATION RATIO

It is evident from the evaporation-precipitation ratio given in Table 6 that evaporation from free water surface is from two to six times as heavy as rainfall over a greater part of the State. It is only in the Konkan that it is equal to or less than the rainfall. Judging from this ratio, the rain in Konkan is likely to be most efficient in leaching the soils and least efficient in north Gujarat and the east Deccan plateau. Even in monsoon months when the rate of evaporation is considerably reduced, the ratio is high all over the State except in the Konkan and in areas, like Belgaum, adjoining the Western Ghats.

TABLE 8

Climatic single values

	Lang's Rain Factor	Meyer's NS Quotient	Vilensky's Precipitation evaporation ratio	Thornthwaite's PE index	Thornthwaite's TE index
Gujarat					
Deesa	23	43	0.17	29	146
Viramgam	—	—	0.18	—	—
Ahmedabad	26	50	0.25	36	152
Dohad	27	—	—	34	141
Baroda	39	89	—	50	143
Surat	39	98	0.30	52	147
Deccan					
Jalgaon	29	—	0.24	38	146
Dhulia	18	—	—	—	—
Malegaon	21	43	—	25	140
Niphad	—	—	0.20	—	—
Ahmednagar	24	48	0.17	27	138
Sirur	19	—	—	—	—
Kirkee	20	—	—	—	—
Poona	27	67	0.26	32	135
Satara	44	—	—	—	—
Miraj	26	66	—	31	136
Kolhapur	38	—	—	—	—
Sholapur	26	48	0.16	32	146
Karnatak					
Bijapur	20	42	—	24	142
Kaladgi	17	—	—	—	—
Dharwar	33	—	0.26	—	—
Gadag	24	61	—	29	139
Belgaum	55	173	0.55	70	127
Konkan					
Bombay	67	263	0.85	82	145
Alibag	84	—	—	121	141
Karjat	—	—	1.90	—	—
Dapoli	112	—	—	—	—
Ratnagiri	97	344	—	147	144
Vengurla	107	—	—	—	—
Maramgao	90	377	1.93	137	144

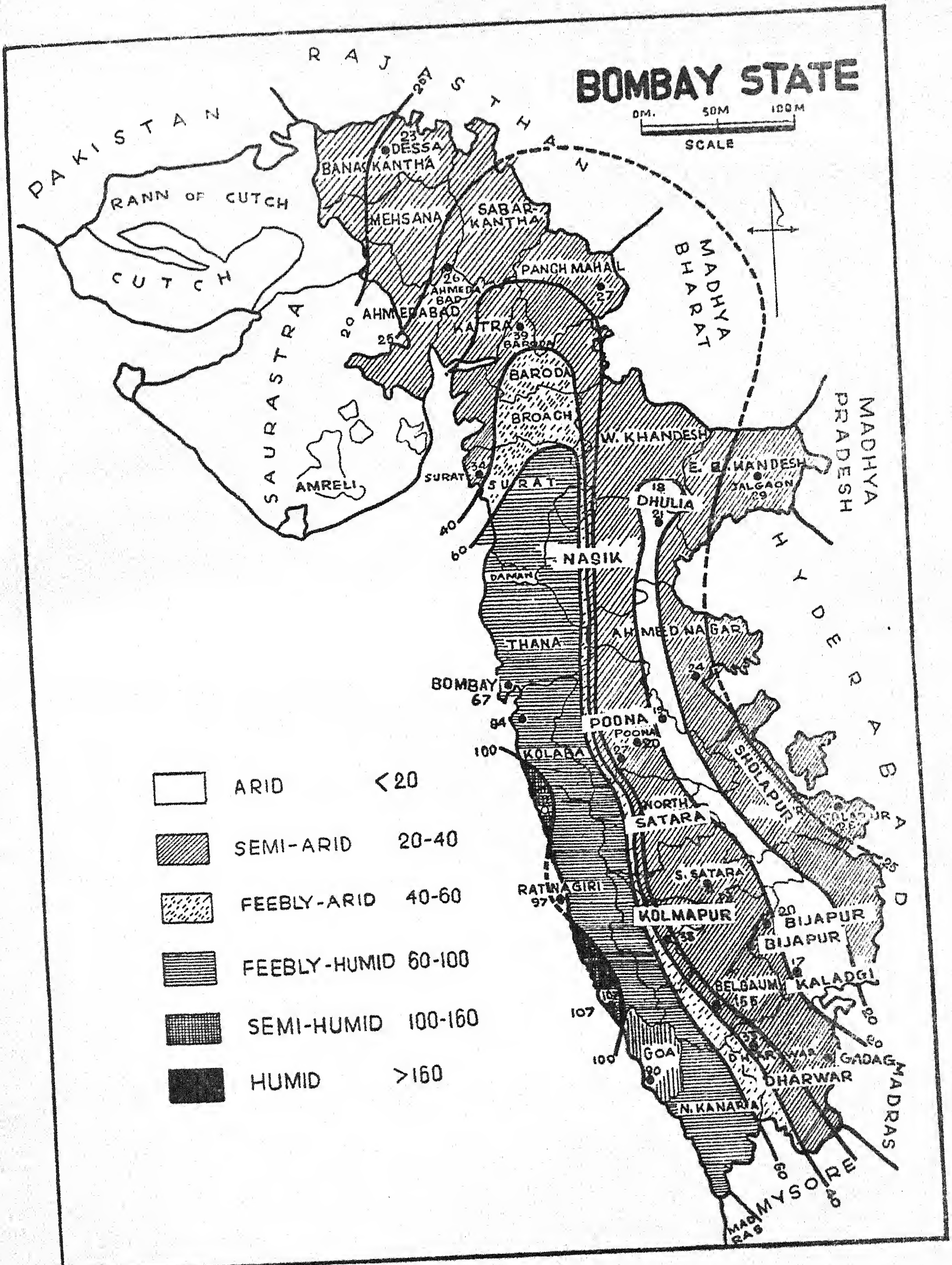

Fig. 3.—Lang's rain factor

CLIMATIC ZONES

Many attempts have been made to devise schemes for correlating climate with the nature of soil developed in a given region. Climate is such a complex phenomenon that no single numerical value can be assigned to it. In spite of its complexity, the two dominant climatic elements, viz., precipitation and temperature, have been used by various workers to study the effect of climate on soil development. Some of the single values calculated from the climatic data available for a few stations in the Bombay State are given in Table 8.

Lang has proposed the use of Rain Factor. It is obtained by dividing mean annual precipitation in millimeters by mean annual temperature in degrees Centigrade. The distribution of the stations according to Lang's Rain Factor is shown in Fig. 3. The whole State can be divided into three climatic regions: (1) the eastern tract having the Rain Factor 0—40, (2) the middle tract having the Rain Factor 40—60 and (3) the western tract having the Rain Factor 60-100. All stations to the north and east of the 40 iso-RF line which extends from Baroda in the north to Dharwar in the south lie in a semi-arid zone. A thin arid zone having the Rain Factor less than 20 seems to run along the whole length of the Deccan plateau from Dhulia in the north to Kaladgi in the south. The whole of the western coast from Surat downwards has a feebly humid to semi-humid climate. The rest of the area lying between 40 and 60 iso-RF lines may be said to have a feebly arid climate.

Meyer has proposed NS quotient* for correlating climatic zones with soil groups. It is obtained by dividing the mean annual precipitation in millimeters by the absolute saturation deficit of air (millimeters mercury). According to his classification which is applicable mainly to temperate regions, regions having NS quotient less than 100 have a desert or arid climate. An NS quotient of 200 is taken as the boundary between arid and humid zones. The distribution of the stations in the Bombay State according to the NS quotient follows more or less the same pattern as Lang's Rain Factor.

The precipitation-evaporation ratio has been used by some workers for the classification of climates. Vilensky (quoted by Jenny, 1941) has developed a climatic classification based on P:E ratio as under :—

P : E ratio	*Climatic zone*
0.00-0.25	Arid
0.25-0.75	Semi-arid
0.75-1.25	Feebly arid
1.25-1.75	Semi-humid
1.75-2.25	Humid

Most of the stations in the Bombay State have a P : E ratio less than 0.75 indicating an arid to semi-arid climate. They lie in a region which corresponds to the area north and east of the 40 iso-RF line in Fig. 3. As the number of stations for which the data in the rest of the area is available is too small it is not possible to demarcate the climatic zones in the rest of the State more clearly.

*Niederschlag/Sattigungsdefizit

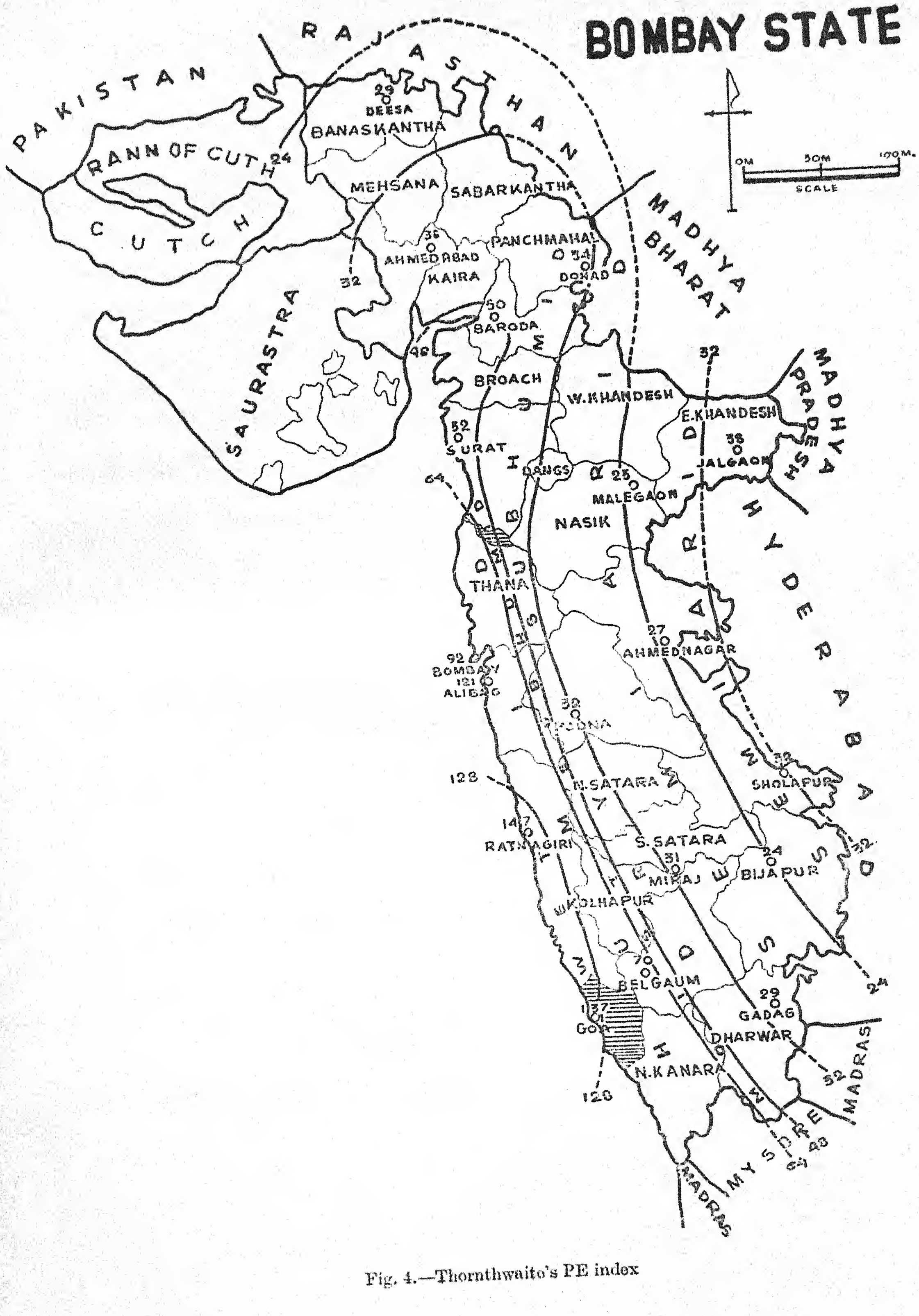

Fig. 4.—Thornthwaite's PE index

Thornthwaite has proposed a climatic classification based on precipitation effectiveness (PE index) and temperature efficiency (TE index) as under :

PE index	*Climatic zone*
0- 16	Arid
16- 32	Semi-arid
32- 48	Dry sub-humid
48- 64	Moist sub-humid
64-128	Humid
>128	Wet

According to his classification the State can be divided into three main regions more or less parallel to each other extending from north to south (Fig. 4). The easternmost region having PE index less than 32 has a semi-arid climate, the middle region having PE index 32-64 has a sub-humid climate and the western region having PE index 64-128 may be said to have a humid climate.

All the four systems of classification divide the State into three more or less well defined climatic zones, (1) the eastern zone having a semi-arid to arid climate, (2) the middle zone which may be said to have a feebly arid to feebly humid climate and (3) the western semi-humid to humid zone. They also show the existence of a thin fringe of wet or humid zone especially along the southern coast and a zone of very dry climate bordering on aridity running right in the middle of the Deccan plateau extending almost throughout its length.

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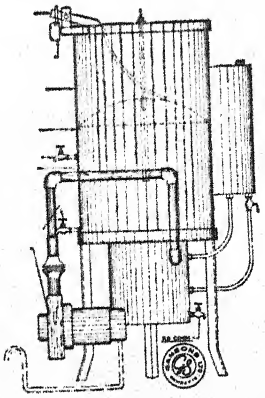

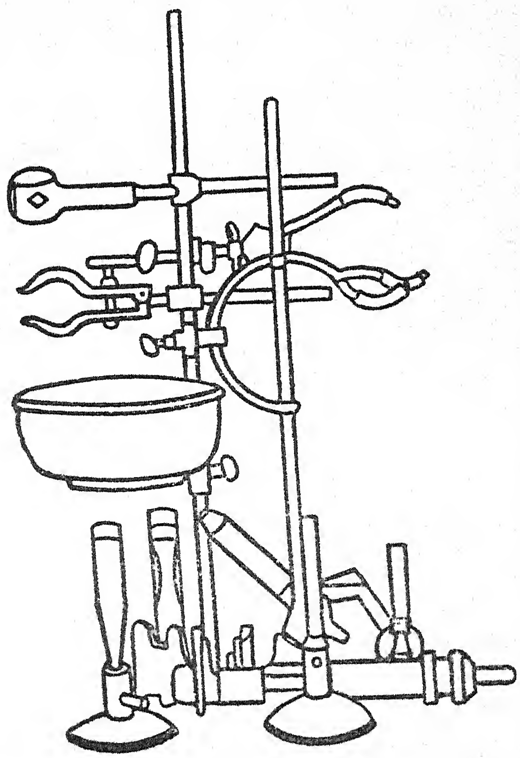

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CONTENTS

Vol. 1, 1953

Vol. 2, 1954

Vol. 3, 1955

Vol. 3, 1955